ESSENTIALS OF MECHANICAL DRAFTING

ELEMENTS — PRINCIPLES
METHODS

LUDWIG FRANK

ESSENTIALS OF
MECHANICAL DRAFTING

ELEMENTS, PRINCIPLES, AND METHODS

WITH SPECIFIC APPLICATIONS IN WORKING DRAWINGS OF
FURNITURE, MACHINE, AND SHEET METAL CONSTRUCTION

A MANUAL FOR STUDENTS

ARRANGED FOR REFERENCE AND STUDY IN CONNECTION WITH COURSES IN MANUAL TRAINING, INDUSTRIAL, HIGH, AND TECHNICAL SCHOOLS

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PREFACE

The purpose of this book is to provide the student with definite comprehensive text and illustrations comprising the theory and practice of mechanical drafting, which shall effectively supplement and give emphasis to the work of the teacher, and at the same time afford complete freedom in the presentation and application of principles to meet different requirements, conditions, and individual needs.

In view of this purpose, and for greater convenience of reference and connected study of related subject-matter, the text is presented in a progressive series of topically arranged articles with appropriate cross references.

This arrangement is not intended, however, as a prescribed order of study to be rigidly adhered to, nor is the content of the text intended to supersede necessary personal instruction or thoughtful study on the part of the student.

The book is designed to be used as the teacher may determine in connection with his own course; to conserve the time and energy usually expended in repetition; to secure a systematic study of such text and illustrations as relate to the oral presentation; and to enable the student to review any desired topic as individual need arises and to proceed with the minimum of dependence upon the teacher.

It is believed that the content and arrangement will be found adaptable and adequate wherever mechanical drafting is taught; will assist the teacher in formulating specific courses; will stimulate the interest of the student by giving a greater appreciation of the utility and scope of the subject; and will prove an efficient aid in developing a working knowledge of the elements, principles, and methods of drafting as applied in general practice.

The writer gratefully acknowledges his obligations to numerous engineers and draftsmen, and to the following directors and teachers of Boston, for many helpful suggestions: Mr. Arthur L. Williston, Director of Wentworth Institute; Mr. John C. Brodhead, Associate Director of Manual Arts; Mr. Edw. C. Emerson, Assistant Director of Manual Arts; Messrs. R. H. Knapp and E. H. Temple of the Mechanic Arts High School; Messrs. A. Roswall and E. M. Longfield of the Boys' Industrial School; Mr. A. L. Primeau, formerly of the South Boston Prevocational Center; and Mr. R. A. Day of the Hyde Park Co-operative Classes. Messrs. Temple, Primeau, and Day also gave valuable assistance in the preparation of the drawings.

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SYMBOLS AND GENERAL ABBREVIATIONS

$\parallel$	parallel; $\parallel$s parallels
$\perp$	perpendicular; $\perp$s perpendiculars
$\angle$	angle; $\angle$s angles
$\triangle$	triangle; $\triangle$s triangles
$\odot$	circle; $\odot$s circles
C. L.	center line; C. Ls. center lines
diam.	diameter; diams. diameters
hor.	horizontal; hors. horizontals
pt.	point; pts. points
rad.	radius
st.	straight
vert.	vertical; verts. verticals

ESSENTIALS OF MECHANICAL DRAFTING

CHAPTER I

INTRODUCTION

1. Nature and Uses of Mechanical Drafting. Mechanical drafting or mechanical drawing is the art of making the conventional representations used by engineers, architects, and inventors in working out and recording the details of their constructive designs, and the means by which ideas of the exact form or shape, dimension, and arrangement of parts in objects of a structural character are universally expressed and made intelligible to others.

Mechanical drafting enables constructive work of any kind to be carried on with accuracy and economy of time and material, and takes the place of lengthy verbal description which would fail to express with clearness and exactness the definite information required by the workman.

It will be seen from Fig. 179 that certain general peculiarities of the form and structure of an object may be understood from an ordinary pictorial representation, but that it cannot show the exact form, size, and relation of *all* the lines and surfaces; hence the necessity for *mechanical drawings* which show all hidden as well as visible parts of an object as they *are* and not as they would appear to the eye.

Mechanical drafting is thus the graphic language of the constructive or mechanic arts, and ability to read or comprehend mechanical drawings is of as great importance to the workman, builder, and manufacturer as ability to make such representations is to the designer or draftsman; and a knowledge of general drafting principles is of value to almost all men irrespective of their vocations.

Because of the exact nature of the facts which it is intended to record or convey the drawing is generally executed with the aid of instruments.

The mechanical character of the representation, together with its purpose and the usual means of execution, gives mechanical drafting its name.

Machine drafting, architectural drafting, and *engineering drafting* are specific applications of mechanical drafting.

A mechanical drawing properly dimensioned in figures and prepared as a guide in constructing the object is called a *working drawing.*

2. Geometric Terms, Definitions, etc. *Geometry* is the science which describes the definite figures (forms or shapes) upon which all objects however complex are based, and the principles and methods by which these figures may be measured and graphically constructed.

Geometry is thus fundamental in mechanical drafting and in all the constructive arts.

The terms defined in this chapter are commonly involved in both.

(a) General Definitions. A physical solid or material object occupies a certain portion of space and has shape, size, weight, color, etc. Geometry is concerned simply with the shape and size of the space which a physical solid occupies or is conceived to occupy; hence—a *geometric solid* is a limited portion of space.

A solid has *dimensions* or extent in three principal directions at right ∠s to each other; namely, *length, breadth* (or *width*), and *thickness* (*height, altitude,* or *depth*).

The boundaries of a solid are called *surfaces.*

A surface has only two dimensions: length and breadth (or width).

The boundaries of a surface are called *lines.*

A line has only one dimension: length.

The limits or ends of a line are called *points.*

A point has position but no dimension.

Points, lines, and surfaces may be considered as apart from a solid, or as combined in any conceivable figure; also a line may be imagined as generated by a point, a surface by a line, and a solid by a surface, in motion.

Similar figures are those having the same shape; *equivalent figures* those having the same size; and *equal* or *congruent figures,* those having the same shape and size.

A figure that lies wholly in one plane is a *plane figure.* (See Art. (h).) A figure whose lines are straight is *rectilinear;* one whose lines are curved is *curvilinear.*

The *axis of a figure* is a st. line which passes through its center, and about which it is symmetrical or balanced.

An *axis of revolution* is a st. line about which a figure is revolved.

When two lines, two surfaces, or a line and a surface meet or cross they are said to *intersect* or *cut* each other and the pt. or line in which they intersect is their *intersection.*

A *bisector* is a pt., line, or plane which divides a figure into two equal parts, that is, *bisects* it. To *trisect* is to divide into three equal parts; to *quadrisect,* into four equal parts.

Fig. 1

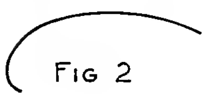


Fig 2

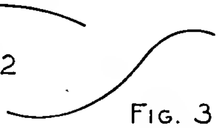


Fig. 3

Fig 4

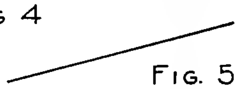


Fig. 5

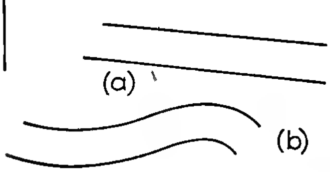


Fig. 6

(b) Lines. A *straight* or *right line* has the same direction throughout. Fig. 1.

A *curved line* or *curve* is one no part of which is straight. Fig. 2.

A *reversed curve* is one whose direction of curvature changes. Fig. 3.

A *horizontal line* is one that is level throughout. In drawing, the term is applied to a st. line drawn from left to right, without slant. Fig. 1.

A *vertical line* is one that is upright or plumb. In drawing, the term is applied to a st. line drawn from bottom to top, without slant. Fig. 4.

An *oblique line* is one that slants. Fig. 5.

Two lines having the same relative direction are *parallel* to each other. They are the same distance apart throughout. Fig. 6.

Two st. lines which extend from the same pt. or which would intersect if extended, are said to be *at an angle* with each other (Fig. 7), and are *perpendicular*, or *oblique*, to each other according as the included ∠ is a right ∠ or an oblique ∠. See Art. (c).

Two curves, or a st. line and a curve, are *tangent* to each other when they touch in but one pt. and cannot intersect. The pt. is the *point of tangency*. Figs. 11(a), 12, 14.

An *ordinate* or *offset* is the ⊥ distance of a pt. from a given st. line, or plane, of reference. A-1, B-2, etc., Fig. 103.

Co-ordinates are ordinates of the same pt., measured || to two, or three, mutually ⊥ lines, or planes, of reference. C-C^V, C-C^H, C-C^P, Fig. 118.

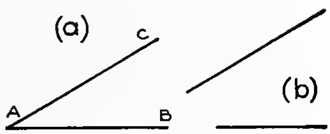


FIG. 7

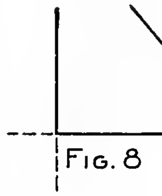


FIG. 8

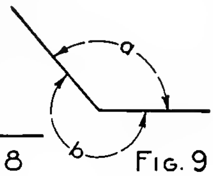


FIG. 9

(c) ANGLES. These definitions refer to plane ∠s only.

An *angle* is the opening between two st. lines, called the *sides* of the angle, which extend from a pt. called the *vertex*. BAC, Fig. 7. An angle may be considered as generated by a st. line revolved about one of its ends.

The size of an angle depends upon the relative direction of the sides and not upon their length. When the sides extend in opposite directions, so as to lie in the same st. line, the ∠ is a *straight angle*. When the directions are such that the ∠s formed by extending the sides beyond the vertex are equal, each ∠ is a *right angle*. A right ∠ is equal to half a st. ∠. Fig. 8.

An ∠ less than a right ∠ is an *acute angle* (Fig. 7); one greater than a right ∠ and less than a st. ∠ is an *obtuse angle* (Fig. 9); one greater than a st. ∠ and less than two st. ∠s is a *reflex angle*. Note that two st. lines extending from a pt. always form two ∠s, as ∠a and ∠b, Fig. 9.

Angles other than right and straight ∠s are *oblique angles*.

Two ∠s having the same vertex and a common side between them are *adjacent angles*. DCF and FCE, Fig. 10.

When two st. lines intersect, the opposite or non-adjacent ∠s are equal and are called *vertical angles*. GCD and FCE, also ∠s DCF and ECG, Fig. 10.

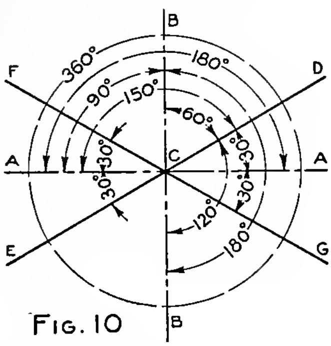


FIG. 10

An angle is said to be measured by an arc, described from its vertex as center and included by its sides. The unit of measure is an angle whose arc is a degree ($\frac{1}{360}$ of a circumference). (See Art. (d).) Thus a st. ∠ is one of 180°, a right ∠ one of 90°, and the whole angular space about a pt. in a plane equals 360°. See Fig. 10.

Lines can be drawn in four directions from a given pt., at the same given ∠ with a given line; thus in Fig. 10, C-D, C-E, C-F, and C-G each make an ∠ of 30° with A-A. Each of these lines makes two ∠s with the hor. A-A and two with the vert. B-B. Thus C-D makes ∠s of 150° and 30° with A-A, and 60° and 120° with B-B.

In speaking of the ∠s formed by two lines, the lesser is the one usually named, and, unless otherwise stated, a line at 15°, 30°, 45°, etc., is understood to mean 15°, 30°, 45°, etc., with the hor. direction.

(d) Curvilinear Figures. A *circle** is a plane figure bounded by a curve called its *circumference*, all pts. of which are equidistant from a pt. within called the *center*. Fig. 11(a).

Any part of a circumference is an *arc*.

A st. line intersecting a circular curve in two pts. is a *secant*, F-G. A st. line joining two pts. in the curve is a *chord*, H-I, A-B.

A chord through the center is a *diameter*.

A straight line from the center to the curve is a *radius*, C-A, C-D, C-E.

A *segment* is a portion of a ⊙ bounded by an arc and its chord.

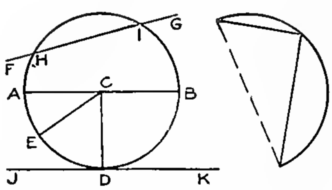
A segment equal to half a ⊙ is a *semicircle**.

A *sector* is a portion of a ⊙ bounded by an arc and two radii.

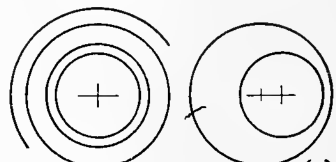
A sector equal to one-fourth of a ⊙ is a *quadrant**.

An ∠ formed by two chords from the same pt. is an *inscribed angle*. Fig. 11(b). An angle is inscribed in a segment when its sides join the ends of the arc.

The ∠ included by two radii is a *central angle*.



(a) Fig. 11 (b)



(a) Fig. 13 (b)

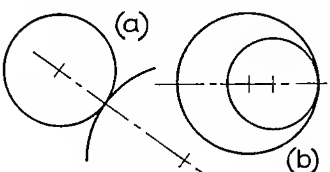


Fig. 12

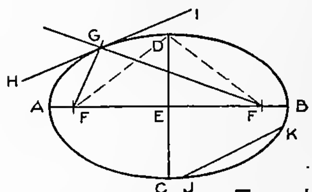


Fig. 14

The circumference of a ⊙ is conceived to contain 360 equal parts called *degrees* (360°), each degree 60 equal parts called *minutes* (60′), and each minute 60 equal parts called *seconds* (60″).

A st. tangent is ⊥ to a rad. at the pt. of tangency. J-K, Fig. 11(a). The pt. of tangency of two circular curves is in their *line of centers*. Fig. 12.

Two circles or arcs having the same center are *concentric*. Fig. 13(a).

Two circles not having the same center are *eccentric* when one is within the other. Fig. 13(b).

An *ellipse** is a plane figure bounded by a curve called its *circumference*, the sum of the distances of every pt. of which, from two pts. within, called the *focuses* or *foci*, is constant. Fig. 14.

A pt. midway between the foci is called the *center*.

A st. line joining any two pts. in the curve is a *chord*.

A chord through the center is a *diameter*.

A diam. containing the foci and center is the *long* or *major axis*. A diam. ⊥ to the major axis is the *short* or *minor axis*. The major and minor axes are the longest and shortest diameters of the ellipse and bisect each other at the center.

A st. line from either focus to any pt. in the curve is a *focal radius*.

The sum of the focal radii of any pt. is equal to the major axis.

A st. tangent bisects the ∠ between one focal rad. and the other extended at the pt. of tangency. When one diam. is ∥ to the tangents at the ends of another, the diams. are *conjugate* to each other.

*The terms "circle," "semicircle," "quadrant," and "ellipse" are also used to denote merely the curve.

(e) Polygons. These definitions refer to plane polygons only.

A *polygon* is a plane figure bounded by st. lines called its *sides*. The sum of the sides is the *perimeter;* the ∠s formed by the sides are the *angles;* and the vertices of the ∠s, the *vertices* of the polygon. Figs. 15-30.

A polygon is *equilateral* when all of its sides are equal (Figs. 15, 24, 27); *equiangular* when all its ∠s are equal (Fig. 21); *regular* when both equilateral and equiangular (Figs. 15, 22, 28-30); otherwise, it is *irregular*.

The *base* of a polygon is the side upon which it is supposed to rest. In general any side may be considered as the base.

The *altitude* is the ⊥ distance between the base, or base extended, and the farthermost vertex or side. A-B in Figs. 15, 17, 19, 23, 26.

A *diagonal* is a st. line joining any two non-consecutive vertices. A-B, Fig. 21; A-B and A-C, Fig. 29.

A polygon is *inscribed* in a ⊙ when all its sides are chords of the ⊙, and *circumscribed* about a ⊙ when all its sides are tangents of the ⊙. Also the ⊙ is circumscribed about the inscribed polygon and inscribed in the circumscribed polygon. Fig. 28.

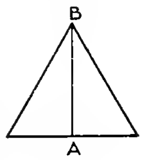


Fig. 15

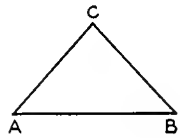


Fig. 16

The *center* of a regular polygon is the center of the inscribed or circumscribed ⊙.

The rad. of the inscribed ⊙ is the *apothem,* and the rad. of the circumscribed ⊙ the *radius* of the polygon. Fig. 28.

In a regular polygon of an even number of sides the diameter of the inscribed ⊙ is often called the *short diameter*, and that of the circumscribed ⊙ the *long diameter* of the polygon.

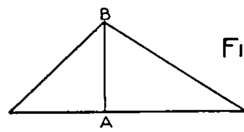


Fig. 17

The sum of the ∠s of any polygon is equal to two right ∠s (180°), taken as many times less two as the figure has sides. See Fig. 20.

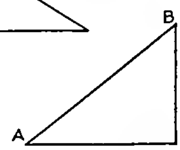


Fig. 18

The ∠ included by the radii to the ends of any side of a regular polygon is called the *angle at the center*. It is equal to 360° divided by the number of sides. Fig. 30.

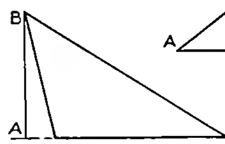


Fig. 19

A polygon of three sides is a *triangle;* of four, a *quadrilateral;* of five, a *pentagon;* of six, a *hexagon;* of seven, a *heptagon;* of eight, an *octagon;* of nine, a *nonagon;* of ten, a *decagon.*

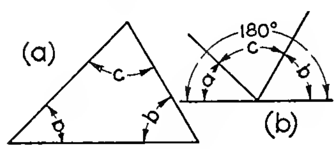


Fig. 20

(f) Triangles. Triangles are classified according to relative length of sides; as *equilateral, isosceles*, and *scalene.*

An *equilateral triangle* has all sides equal; it is also equiangular. Fig. 15.

An *isosceles triangle* has two sides equal; two ∠s are also equal. Fig. 16. The equal sides are usually called the *sides*, and the other side, the *base.*

A *scalene triangle* has no two sides equal; its ∠s are also unequal. Fig. 17.

Triangles are classified according to kind of ∠s; as *right, obtuse,* and *acute.*

A △ is a *right triangle* when one ∠ is a right ∠. Fig. 18. The side opposite the right ∠ is called the *hypotenuse*, the others are usually called the *sides.*

A △ is an *obtuse triangle* when one ∠ is obtuse. Fig. 19.

A △ is an *acute triangle* when all ∠s are acute. Fig. 20(a).

The ∠ opposite the base of a △ is called the *vertex angle,* and its vertex, the *vertex* of the triangle.

(g) Quadrilaterals. A *parallelogram* is a quadrilateral whose opposite sides are ||. Figs. 21-24.

A *rectangle* is a right-angled parallelogram. Figs. 21, 22.

A *square* is an equilateral rectangle. Fig. 22.

A rectangle whose opposite sides only are equal is often called an *oblong.* Fig. 21.

A *rhomboid* is an oblique-angled parallelogram. Figs. 23, 24.

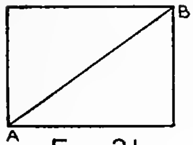


FIG. 21

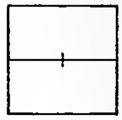


FIG. 22

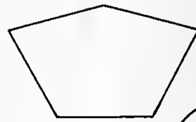


FIG. 27

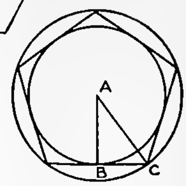


FIG 28

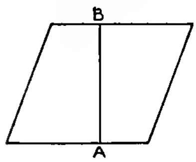


FIG. 23

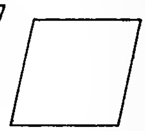


FIG. 24

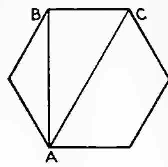


FIG 29

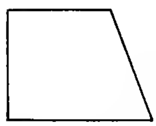


FIG. 25

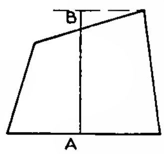


FIG. 26

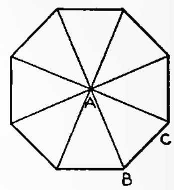


FIG. 30

A *rhombus* is an equilateral rhomboid. Fig. 24.

The side || to the base of a parallelogram is called the *upper base,* the other is the *lower base.*

A *trapezoid* is a quadrilateral which has two sides only ||. Fig. 25. The parallel sides are the *upper* and *lower bases.*

A *trapezium* is a quadrilateral which has no two sides ||. Fig. 26.

(h) SURFACES. A *plane surface* or *plane* is a surface such that a st. line through any two pts. in it lies wholly in the surface.

A *curved surface* is one no part of which is plane. If a semicircular arc be revolved about its chord, it will generate a *spheric surface.* Fig. 46.

A st. line which moves || to its first position and constantly touches a fixed curve not in the plane of the line, will generate a *cylindric surface.* Fig. 39.

A moving st. line which constantly intersects a fixed curve and passes through a fixed pt. not in the plane of the curve will generate a *conic surface.* The fixed pt. is its *vertex.* Fig. 43.

Curved surfaces generated by st. lines are *single curved surfaces.* The generating line in any of its positions is called an *element.*

A *warped surface* is one of single curvature in which no two consecutive elements are || or intersecting. A in Fig. 158.

A *double curved surface* is one generated by a curve of which no two consecutive positions are ||; as the surface of a sphere, ellipsoid, etc. Figs. 46, 47.

A curved surface generated by the revolution of a line about an axis is called a *surface of revolution;* as a right circular cylindric or conic surface, etc. Figs. 39, 43, 46, 47. Each pt. of the generating line describes a $\odot$ whose plane is $\perp$ to the axis.

A plane surface is *horizontal* when it is level throughout; *vertical* when $\perp$ to a hor. plane; *oblique* when neither hor. nor vert.

Two surfaces, or a line and a surface, are *parallel* when they are the same distance apart throughout.

Two plane surfaces which extend from the same st. line or which would intersect if extended, are said to be *at an angle* with each other; and are *perpendicular,* or *oblique,* to each other according as the included $\angle$ is a right or an oblique dihedral.

A *dihedral* or *dihedral angle* is the opening between two planes called the *faces* of the angle, which intersect in a st. line called its *edge.*

A dihedral is measured by the plane $\angle$ formed by two st. lines, one in each face and $\perp$ to the edge at the same pt.

A dihedral is *right, acute,* or *obtuse* according as its measure is a right, acute, or obtuse plane ∠.

A st. line and a plane are ⊥ to each other when the line is ⊥ to every st. line through its foot or pt. of intersection with the plane.

The ∠ a line makes with a plane is the ∠ which it makes with a line in the plane passing through its foot and the foot of a ⊥ from any other pt. in the line.

A plane and a curved surface, or two curved surfaces, are *tangent* when they touch in but one pt. or in one line, and cannot intersect. The pt. or line is the *point* or *line of tangency.*

A st. line or curve and a curved surface, or a curve and plane, are tangent when they touch in but one pt. and cannot intersect.

(i) Solids. The *base* is the plane surface of the solid upon which it is supposed to rest.

The *altitude* is the ⊥ distance between the plane of the base and the farthermost vertex or part.

A *plinth* is a prism, or cylinder, whose altitude is its least dimension. Figs. 33, 42.

A *plane section* is the figure formed by the intersection of a solid with a plane passing through it.

A *solid of revolution* is one which may be generated by a plane surface revolving about an axis.

A solid bounded by plane surfaces is called a *polyhedron.* Figs. 31-38. The bounding surfaces are its *faces;* the intersection of its faces, the *edges;* and the vertices of the faces, the *vertices* of the polyhedron.

A *diagonal* of a polyhedron is a st. line joining any two vertices not in the same face, as A-B, Fig. 31(a).

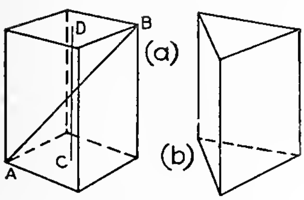


Fig. 31

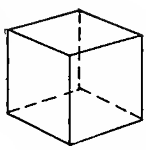


Fig. 32

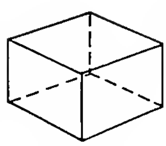


Fig. 33

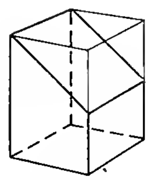


Fig 34

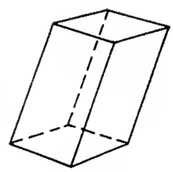


Fig. 35

(j) Prisms. A *prism* is a polyhedron bounded by two equal polygons called its *bases,* and by three or more parallelograms called its *lateral faces.* The intersections of its lateral faces are its *lateral edges;* the others are its *base edges.* Figs. 31, 32, 33, 35.

Prisms are named from their bases; as *triangular, square,* etc.

A prism whose base centers lie in a ⊥ to its bases is a *right prism.* Figs. 31-33. All others are *oblique.* Fig. 35.

A *regular prism* is a right prism whose bases are regular polygons. Its lateral faces are equal rectangles.

A *cube* is a regular prism whose six faces are equal squares. Fig. 32.

A *right section* of a prism is a section ⊥ to its lateral edges.

A *truncated prism* is the portion of a prism included between a base and a section oblique to the base. Fig. 34.

(k) Pyramids. A *pyramid* is a polyhedron bounded by a polygon called its *base,* and three or more △s called its *lateral faces,* meeting in a common pt. called the *vertex* of the pyramid.

The intersection of its lateral faces are its *lateral edges;* the others are its *base edges.* Figs. 36, 37.

Pyramids are named from their bases; as *triangular, square,* etc.

A pyramid whose vertex lies in a ⊥ to the center of its base is a *right pyramid.* Fig. 36. All others are *oblique.* Fig. 37.

A *regular pyramid* is a right pyramid whose base is a regular polygon. Its lateral faces are equal △s.

The altitude of a lateral face of a regular pyramid is the *slant height* of the pyramid. C-B, Fig. 36.

A *truncated pyramid* is the portion of a pyramid included between the base and any plane section. Figs. 38(a) and (b). When the section is || to the base, the included portion is a *frustum* of a pyramid. Fig. 38(a).

(l) Cylinders. A *cylinder* is a solid bounded by a closed cylindric surface called the *lateral surface,* and two || plane surfaces called its *bases.* Figs. 39, 40, 42.

A cylinder is named from its bases; as *circular, elliptic,* etc. The terms "*right,*" "*oblique,*" and "*truncated*" apply to a cylinder as to a prism.

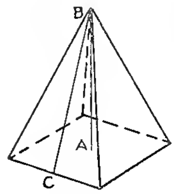


Fig 36

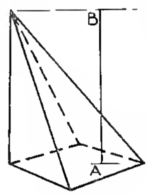


Fig. 37

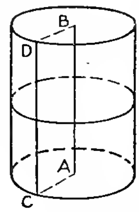


Fig. 39

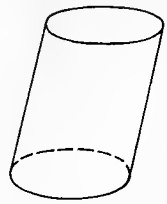


Fig. 40

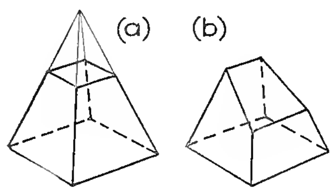


Fig. 38

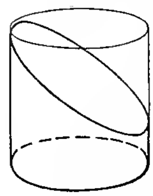


Fig. 41

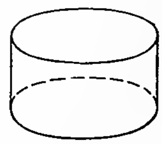


Fig. 42

A *right circular cylinder* may be generated by the revolution of a rectangle about one of its sides. Fig. 39.

A *right section* of a cylinder is a section ⊥ to its elements.

(m) Cones. A *cone* is a solid bounded by a closed conic surface called the *lateral surface,* and a plane surface called its *base.* Figs. 43, 44.

A cone is named from its base; as *circular, elliptic,* etc. The terms "*right,*" "*oblique,*" "*truncated,*" and "*frustum*" apply to a cone as to a pyramid.

A *right circular cone* may be generated by the revolution of a right △ about one of its sides. Fig. 43. The length of an element of a right circular cone is the *slant height.*

(n) A Sphere is a solid bounded by a closed spheric surface every point of which is equidistant from a pt. within called the *center.* Fig. 46. A st. line from the center to the surface is a *radius;* a st. line through the center and terminated at each end by the surface is a *diameter.*

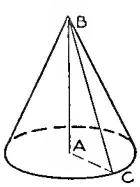


Fig. 43

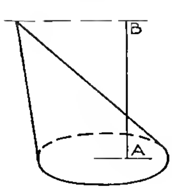


Fig. 44

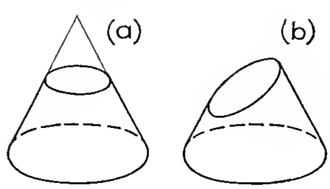


Fig. 45

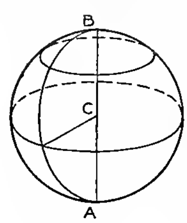


Fig. 46

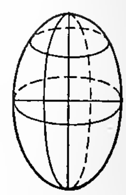


Fig. 47

A sphere may be generated by the revolution of a semicircle about its diam.

A plane section through the center is a *great circle of the sphere.* Any others are *small circles of the sphere.*

Any great ⊙ divides a sphere into two equal parts called *hemispheres.*

A *spheroid* (*ellipsoid*) is a solid which may be generated by the revolution of an ellipse about either its long or short diam. Fig. 47.

(o) Areas and Volumes. The number of times a geometric magnitude contains a given unit of measure of the same kind is the *numeric measure* of the magnitude.

The *ratio* of two magnitudes is the quotient of their numeric measures, expressed in terms of the same unit. Thus the ratio of 2″ to 3″ is $\frac{2}{3}$, or 2 : 3.

The expression of the equality of two ratios is called a *proportion*. As $\frac{2}{3}=\frac{4}{6}$. Read 2 is to 3 as 4 is to 6. The quantities compared are said to be *in proportion* or *proportional*, and are called the *terms*. The first and last terms are the *extremes* and the middle terms, the *means*. In any proportion the product of the extremes equals the product of the means; hence, if three terms are given, the fourth may be found.

The *area* of a surface is its measure expressed in some unit of surface, as a square inch, square foot, etc.

The area (A) of a parallelogram is equal to the product of its base (b) and altitude (a). $A = ba$.

The area of a square is equal to the square of one of its sides (s). $A = s^2$.

The length of the side is equal to the square root of the area. $s = \sqrt{A}$.

The length of the diagonal (d) is equal to the square root of 2 times the square of the side. $d = \sqrt{2 \times s^2}$ or $d = s\sqrt{2}$. ($\sqrt{2} = 1.414$).

The area (A) of a △ is equal to $\frac{1}{2}$ the product of its base (b) and altitude (a). $A = \frac{1}{2}ba$.

The altitude (a) of an equilateral △ is equal to $\frac{1}{2}$ the product of the side (s) and the square root of 3. $a = \frac{s\sqrt{3}}{2}$. ($\sqrt{3} = 1.732$).

The hypotenuse (h) of a right △ is equal to the square root of the sum of the squares of the other two sides (b) and (c). $h = \sqrt{b^2 + c^2}$.

The area of a trapezoid is equal to $\frac{1}{2}$ the product of its altitude (a) and the sum of its bases (b) and (b′). $A = \frac{1}{2}a\,(b+b')$.

Any polygon may be divided into △s. The area of the polygon is equal to the sum of the areas of its △s.

The length of the circumference (c) of a ⊙ is equal (very nearly) to 3.1416 times the length of the diameter (d). 3.1416 is designated by the Greek letter (pi). $c = \pi d$ or $2\pi r$.

The area of a ⊙ is equal to π times the square of its rad. (r). $A = \pi r^2$.

The *volume* of a solid is its measure expressed in some unit of volume, as a cubic inch, cubic foot, etc.

The volume (V) of a cube is equal to the cube of its edge (s) or third power of its dimension. $V = s^3$.

The volume of a prism, or cylinder, is equal to the product of its base (b) and altitude (a). $V = ba$.

The lateral area (l) of a prism, or cylinder, is equal to the product of a lateral edge or element (e), and the perimeter (p) or circumference (c), of a right section. $l = ep$, or $l = ec$.

The volume of a pyramid, or cone, is equal to $\frac{1}{3}$ the product of its base and altitude. $V = \frac{1}{3}ba$.

The lateral area of a regular pyramid, or right circular cone, is equal to $\frac{1}{2}$ the product of its slant height (s) and the perimeter, or circumference, of its base. $l = \frac{1}{2}sp$, or $l = \frac{1}{2}sc = \pi rs$.

The area of the surface (s) of a sphere is equal to the product of the circumference of a great ⊙ and its diam. (d), that is, $2\pi rd$, and is equivalent to the area of 4 great ⊙s. $s = 4\pi r^2$.

The volume of a sphere is equal to the product of $\frac{1}{3}$ of its rad. and the area of its surface, that is, $\frac{1}{3}r \times 4\pi r^2 = \frac{4}{3}\pi r^3$. $V = \frac{4}{3}\pi r^3$ or $\frac{1}{6}\pi d^3$.

Decimal Equivalents of Fractions of an Inch

		1/64	015625			33/64	.515625
	1/32		.03125		17/32		.53125
		3/64	.046875			35/64	.546875
1/16			.0625	9/16			.5625
		5/64	.078125			37/64	.578125
	3/32		.09375		19/32		.59375
		7/64	.109375			39/64	.609375
1/8			.125	5/8			.625
		9/64	.140625			41/64	.640625
	5/32		.15625		21/32		.65625
		11/64	.171875			43/64	·671875
3/16			.1875	11/16			.6875
		13/64	.203125			45/64	.703125
	7/32		.21875		23/32		.71875
		15/64	.234375			47/64	.734375
1/4			.25	3/4			.75
		17/64	.265625			49/64	.765625
	9/32		.28125		25/32		.78125
		19/64	.296875			51/64	.796875
5/16			.3125	13/16			.8125
		21/64	.328125			53/64	.828125
	11/32		.34375		27/32		.84375
		23/64	.359375			55/64	.859375
3/8			.375	7/8			.875
		25/64	.390625			57/64	.890625
	13/32		.40625		29/32		.90625
		27/64	.421875			59/64	.921875
7/16			.4375	15/16			.9375
		29/64	.453125			61/64	.953125
	15/32		.46875		31/32		.96875
		31/64	.484375			63/64	.984375
1/2			.5				

3. General Instructions for Working Out Problems. In the solution of graphic problems clear mental images of the forms to be represented, definite ideas of the purpose of the drawings, and the orderly application of appropriate principles and working methods, are fundamental.

Habits of *accuracy, thoroughness*, and *neatness* should be cultivated from the outset as the essentials of good workmanship. The value of the work lies not in the completed drawings, but in the knowledge and ability acquired by the student through his own efforts in solving problems and in striving to attain mastery of the principles and methods which will enable him to represent any form whether real or imaginary.

Upon the presentation of a problem the student should first form a definite idea of what is *required*, the conditions and principles involved, and the method of construction to be employed. He should then start the drawing, beginning with the parts that are *known* or *given*. These will suggest other parts. It is not necessary to imagine the complete solution before beginning to draw.

Test and correct each stage of the solution before proceeding with the next. Upon the completion the student should make a brief notebook summary for future reference.

For use of instruments and materials, see Chap. II.

For general instructions in penciling and finish rendering, see Chap. III.

(a) Geometric Construction Sheets. Chap. IV. Unless otherwise directed solve problems by *practical methods* whenever such are known or given. Within reasonable limits prove or test the constructions by *geometric methods*, using compasses and one triangle only; and retain all working lines. Make constructions as large as practicable to insure greater accuracy, and extend the working lines beyond the pts. as shown in the figures.

To avoid impairing the accuracy of the constructions, it is recommended that they be left in pencil.

(b) Orthographic Projection Sheets. Chaps. V-VIII. Locate first the traces of the planes, or equivalent lines of reference (base or C. Ls.). Then proceed to determine the views, beginning in general with that view or part about which most is known; in the case of an object, for example, the view which will show the largest number of the lines and surfaces of the object in their exact form and dimension. Instead of completing the views separately it is usually desirable to carry along the views of corresponding parts at the same time. Unless otherwise directed use practical rather than geometric methods for the constructions, and obtain the solutions by the aid of dimensioned freehand sketches from objects. See Art. 104.

To determine the positions of the lines and surfaces more readily, number or letter each pt. lightly as located, marking the corresponding views to indicate that they represent the same pt. of the object. In locating positions of centers or other important pts., small freehand ⊙s may be penciled about them. When the drawing has been approved, these notation marks and ⊙s should be erased.

(c) Isometric and Oblique Projection Sheets. Chap. IX. Locate first the axes, or reference lines, then locate the main lines or surfaces of the object. Gradually work from these to the more important details, then proceed to the smaller details.

Obtain the dimensions from objects; exact orthographic views; working drawings; or from dimensioned sketches in orthographic, isometric, or oblique projection, as may be directed.

(d) Working Drawings. Chap. X. Locate first the main C. Ls. of the views according to the layout sketch (Art. 105 (a)), then locate the main lines or surfaces of the object, as indicated in Fig. 209 (a), beginning with the view about which most is known, as in Art. (b).

Proceed in like manner with the more important modifications or details of the main body (Fig. 209 (b)) and from these work down to the smaller details. Next, add the dimension and extension lines, arrowheads, figures, and lettering. Fig. 209 (c), (d). Finally indicate the section lines. Do not try to complete the views separately. Within practical limits those of corresponding parts should be carried along at the same time. Use practical methods for the constructions whenever adequate.

Obtain the working data from dimensioned sketches made from objects, or as directed.

For methods of representing the commoner forms of bolts, screws, etc., see Chap. XI. For tables of sizes, and the construction and proportions of other machine details, see manufacturers' catalogs, books on machine design, and engineers' handbooks. For sizes, etc., of details of wood construction, see books on joinery, etc.

CHAPTER II

INSTRUMENTS, MATERIALS, AND THEIR USE

4. List of Equipment. The instruments and materials ordinarily needed are enumerated in the following. A good equipment is indispensable to good work. If not furnished by the school, its selection should be intrusted to an experienced draftsman.

Set of Instruments, consisting of Compasses $5\frac{1}{2}''$ (joint in both legs preferred), with Lead Holder, Pen, and Lengthening Bar attachments; Ruling Pen, medium; Dividers, 5″; Bow Pencil; Bow Pen; and Bow Dividers.

Leads, grade 4H, for compasses and bow pencil.

Drawing Board, 18″ x 24″, is suitable for most work.

T-square, fixed head, blade slightly longer than board.

Triangles, one 45°, 7″, and one 30° x 60°, 9″ (celluloid preferred).

Scale, 12″, flat, both edges divided into full size inches, halves, 4ths, 8ths, and 16ths, and the first inch, or first and last, into 32ds.

Or, a 12″ architect's triangular scale: one edge divided into full size inches and fractions, to 16ths, and the others to scales of 3″, $1\frac{1}{2}''$, 1″, $\frac{3}{4}''$, $\frac{1}{2}''$, $\frac{3}{8}''$, $\frac{1}{4}''$, $\frac{3}{16}''$, $\frac{1}{8}''$, and $\frac{3}{32}''$ to 1 foot.

(The flat scale is recommended if scales of full, half, quarter, eighth, and sixteenth sizes only are to be used.)

Curve Rulers, one or two, similar to those shown in Figs. 66, 67 (celluloid preferred).

Drawing Pencils, one hard, grade 4H, 5H, or 6H, and one medium hard, grade H or 2H.

Erasers, one soft rubber for pencil erasing and one hard rubber for ink erasing.

Needle-point, a fine needle inserted in a wooden handle about $3\frac{1}{2}''$ long, for use in fixing pts.

Tacks, 1 oz. copper, or small thumb-tacks, for fastening paper to board.

Tack-driver. A small screw-driver ground to a thin edge and slightly bent at the end will be suitable.

Knife, for pencil sharpening (one with broad blade preferred).

Lead-pointer, a strip of No. $\frac{1}{2}$ sandpaper or No. 120 emery cloth, about $\frac{3}{4}''$ x 4″, glued upon a flat strip of wood.

Penholder and Writing Pens, for lettering, etc. (Tapering handle with cork grip preferred.) Pens should be medium and coarse.

Penwiper, a piece of cloth or wash leather.

Drawing Ink, one bottle waterproof black; writing ink is unsuitable.

Drawing Paper, hard and tough, with a surface not easily roughened by erasures. For sketches a softer paper is desirable. Avoid rolling the paper. Sizes in common use are 18″ x 24″, 12″ x 18″ and 9″ x 12″; also 15″ x 22″, and 11″ x 15″.

Portfolio or Binding Cover, to hold paper and drawings.

Notebook Cover, with loose sheets, about 6″ x 9″.

Cloths, a white cotton cloth about 14″ x 20″, hemmed, to place materials upon; a piece of cloth or wash leather for wiping instruments; and a small dusting cloth.

Box, to hold the pencils, erasers, cloths, and other small articles.

5. Care and Arrangement of Equipment. Next in importance to having good instruments and materials is the necessity of handling them properly, keeping them clean, in good working condition, and in convenient, orderly arrangement.

Keep the fingers clean, and the table and materials free from dust. The T-square and triangles especially will need frequent wiping. A paper or cloth may be fastened over a part of the drawing to protect it while working on other parts.

Keep instrument case, box, and locker closed; and the ink bottle in the stand, with stopper in place.

The instruments must always be carefully wiped, and properly replaced in the case when through working.

Never permit ink to dry in the pens, or upon any part of the equipment.

Take every precaution to insure against injury to the points, shanks, etc., of the instruments; and the edges of the scale, board, T-square, triangles, and curve rulers.

Adjustments of joint-screws in compasses and dividers should be made by the instructor, unless otherwise directed.

Inaccuracy, injury, or loss of any part of the equipment should be reported immediately.

The table should be so placed that the light comes from the left* and, if possible, adjusted to such a height that the student may stand while at work.

6. Drawing Board. The drawing board provides a flat surface upon which to secure the paper, and a st. edge against which to guide the head of the T-square. Either short edge may be selected for this purpose, but the board must be placed so that this edge will be at the left*, and no other used as a guiding edge in elementary work. See Fig. 48.

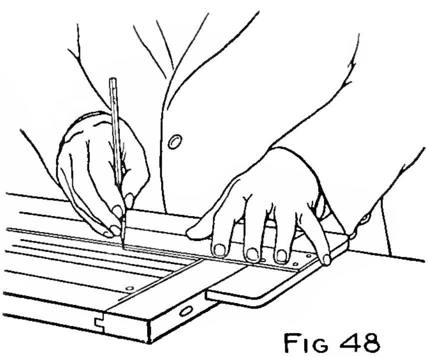


FIG 48

For convenience in working and to insure firmness and freedom in the use of T-square and triangles, the paper should be placed about 3″ from the left* and lower edges of the board.

Square the paper with the board by lining up one of its edges against the ruling edge of the T-square. Art. 7.

Insert tacks about $\frac{3}{16}$″ from each corner, pressing the paper as flat as possible with the hand; then with thumb or tack-driver force the heads flush with the paper, so that they will not interfere with the use of the T-square, etc. Always remove T-square from board when using tack-driver, and avoid marring the board.

After paper is fastened, the board may be inclined by means of a book or block under its farther edge, so that all parts of the drawing may be more nearly at the same distance from the eyes.

Keep paper secured to the board until drawing is completed. If removed before, it should be refitted by inserting a tack in one of its upper corners and lining up the most important horizontal of the drawing against the T-square.

7. T-square. The T-square is used with its head against the left edge of the board. Fig. 48. The upper edge of the blade in this position is the ruling

*In this and similar working directions, left-handed students may read "right" in place of "left."

edge for all hor. lines, and guide for the triangles when drawing lines at certain ∠s. Never use the lower edge of the blade as this would lead to errors difficult to trace. As the ∠ of the head and blade in different T-squares is apt to vary, the same T-square should be used until the drawing is completed.

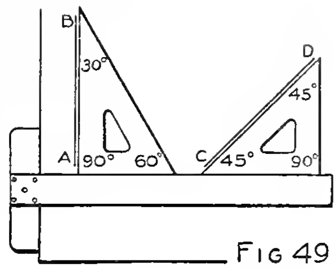


FIG 49

(a) TO DRAW A HORIZONTAL THROUGH A GIVEN POINT. Slide the head along the guiding edge of board until the ruling edge passes through the given pt. For preparation and use of pencil, see Art. 9. Move T-square by the head only, and while drawing the line keep head and blade securely in position by sliding the fingers of the left hand along the blade and pressing towards the right. Fig. 48.

8. Triangles. The triangles (Fig. 49) are used as rulers for lines at ∠s with the hor. direction. The ruling edges of the *45° triangle* form an ∠ of 90° and two of 45° each. Those of the *30° x 60° triangle* form an ∠ of 90°, one of 30°, and one of 60°.

(a) TO DRAW A LINE AT AN ANGLE OF 30°, 60°, 45°, OR 90°. Place one edge of the corresponding 30°, 60°, 45°, or 90° ∠ of the triangle against the T-square and guide the pencil along the other edge of the ∠. Hold T-square and triangle firmly in position with left hand. Fig. 50. When the line to be drawn is longer than the edge, slide the T-square until the required length is obtained.

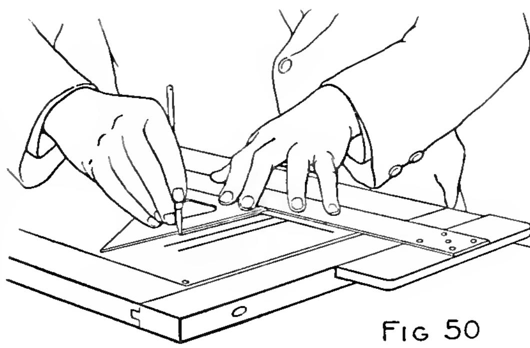


FIG 50

Avoid ruling near the corners, as they are apt to be rounded; thus, in drawing a line, say at 90° with a given hor., place the T-square a little below the hor. as shown. Never rule against the inner edges.

(b) TO DRAW A LINE AT AN ANGLE OF 75° OR 15°. Combine the triangles and T-square as in Fig. 51. The 30° ∠ added to one of 45° gives an ∠ of 75°. By reversing the upper triangle as shown by dotted lines, one of its edges will be at 15°. By placing the 60° angle against one of 45°, a line at 75° or 15° in the opposite direction may be obtained.

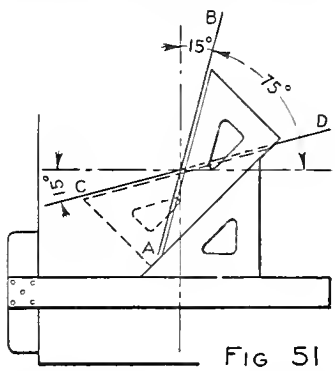


FIG 51

(c) TO DRAW A PARALLEL TO ANY GIVEN LINE.* Combine the triangles with an edge of one (see dotted triangle, Fig. 52) to coincide with the

*When the given line is hor., or at 30°, 60°, 45°, 90°, 75°, or 15° with the hor. direction, the T-square, or triangle and T-square combinations, would ordinarily be used.

given line A-B; then, holding the second securely, slide the first until the edge which originally coincided with A-B is in the required position C-D.

(d) To draw a line at 30°, 60°, 45°, 90°, 75°, or 15° with any given line.*

For 30°, 60°, 45°, or 90°, Fig. 53. Combine the triangles with an edge of one || to the given line A-B, as in (c). Then holding this triangle securely, shift the second, placing it against the || edge of the first, so that one of its edges makes the required ∠ with A-B.

For 75° or 15°, Fig. 54. It is evident that after the second triangle has been placed against the || edge of the first, the first in turn must be shifted to give the required ∠.

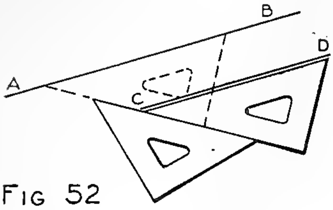


Fig 52

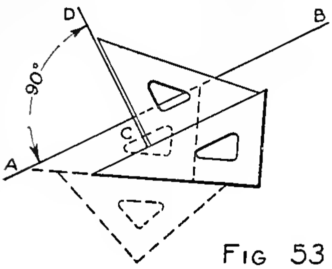


Fig 53

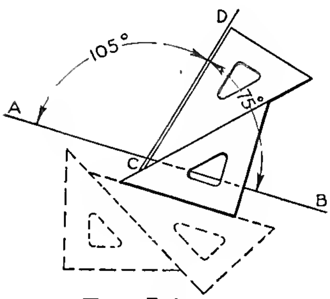


Fig 54

9. **Pencils and Writing Pens.** The hard pencil is used for ruling lines against the T-square, triangles, and curve rulers; the medium pencil for all freehand penciling, lettering, etc., and the pens for inking freehand lines, lettering, etc.

(a) To sharpen the pencils. Sharpen the end not bearing the grade stamp. Hold the inner side of both wrists firmly against the body, with the knife blade nearly flat against the upper side of the pencil and its cutting edge to the right. Cut with an outward wrist movement, removing the wood in long thin shavings, tapering it evenly down to but not cutting the lead, and so that about $\frac{3}{8}''$ of the latter is exposed. Fig. 55. This method gives greater control of the knife and lessens the liability of soiling the fingers. The lead should be pointed by means of a lead-pointer. Hold pointer in the left hand, away from the table, and the pencil so that the entire length of lead will be tapered.

Taper the lead of the freehand pencil to a fairly sharp pt. by rubbing it back and forth, at the same time rolling the pencil between thumb and fingers. Fig. (a).

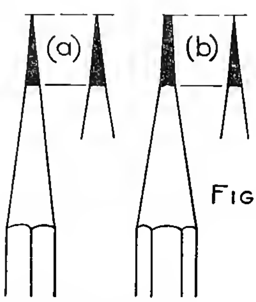


Fig. 55

The lead of the ruling pencil should be tapered to a sharp conic pt., or to a wedge pt., as the instructor directs. The wedge pt. (Fig. b) retains its sharpness longer and fits more closely against the ruling edge. It is obtained by first tapering the lead slightly as for the freehand pt., and then rubbing the lead upon opposite sides to form a short, sharp edge at the end.

Rub the leads frequently to keep them in proper condition.

*When the given line is hor., or at 30°, 60°, 45°, 90°, 75°, or 15° with the hor. direction, the T-square, or triangle and T-square combinations, would ordinarily be used.

(b) USE OF THE FREEHAND PENCIL. Hold pencil lightly, about $1\frac{1}{2}$ inches from the point. The relation of the pencil to the line, and the direction of the stroke, should usually be as indicated in Fig. 56. Face the paper squarely and avoid turning it while drawing.

All lines should be drawn with as few strokes as possible.

Draw lightly at first and correct any portion by drawing a second line before erasing. Finally strengthen the line to make it clear and even. Practice in arm and finger movements before drawing will aid in acquiring necessary freedom.

(c) USE OF THE RULING PENCIL. Hold pencil as nearly upright as possible, with flat side of lead against the ruling edge. Steady pencil in this position by resting the tip of the third or fourth finger upon the ruler. Fig. 48. This permits the edge of the lead to wear evenly and give uniform lines. Bear lightly,—much pressure will dull the lead too rapidly, make uneven lines, or form depressions which cannot be erased. The result should be very fine, clear lines.

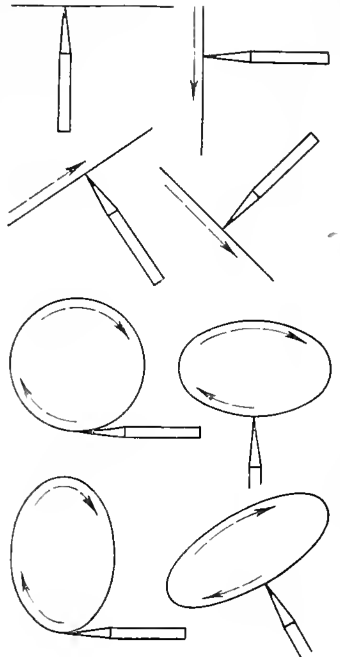


FIG 56

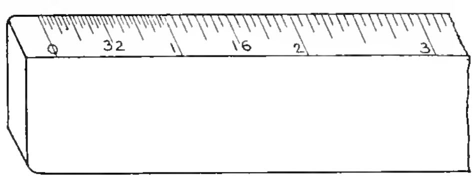
The pencil should always be moved from left to right, the student turning his body or the board when necessary, that he may face the ruling edge squarely and do this more readily. Thus in drawing verts. face to the left, and draw away from the T-square. (See Fig. 50.) If ruled against a right-hand edge, the pencil is apt to glide away from the ruler and cause a break in the line. Watch the point constantly as it is moved along. Never rule a line in a shadow, and never rule backward over a line.

In drawing parallels move the ruler from one position to the other in such manner that the preceding line and space will not be covered. Thus, in drawing || hors., move T-square downwards; in || verts., move triangle to the right.

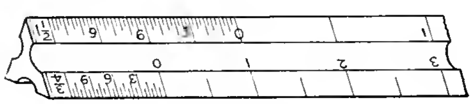
(d) USE OF WRITING PENS. Handle the pen the same as freehand pencil. Use little ink and aim to secure uniform, even lines. Exercise special care in working over lines to avoid injuring the paper.

10. Needle-point. The needle-point is used to set off distances from the scale, and to fix pts. of line intersections which might otherwise be erased or lost. Hold needle upright and make the smallest puncture that can be seen.

11. Scales. The scale is used for setting off measurements. It must never



(a)



(b) FIG. 57

be used as a ruler for drawing lines. The scales shown in Fig. 57 are graduated as described in Art. 4.

(a) When the drawing is made so that each inch or fraction of an inch of measurement upon it is equal to the corresponding measurement on the object itself, the drawing is said to be *full size* or *to a scale of 12″ to a foot.*

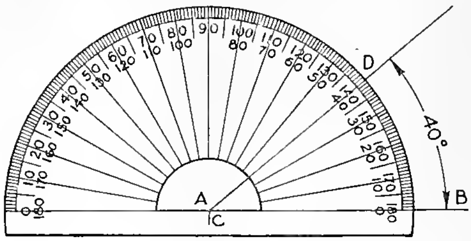


Fig. 58

When for convenience or necessity the drawing is made smaller or larger than full size each unit of measurement is made smaller or larger in proportion,—thus when drawn, say *half size* or *6″ to a foot,* each half inch on the drawing represents one inch on the object; each quarter inch a half, and so on.

Full size measurements are obtained from a scale graduated to full size inches and fractions.

Half size measurements are usually obtained from a full size scale by simply reading each half inch on the scale as one inch, each quarter inch as a half, etc. Quarter, eighth, and sixteenth size can be obtained in like manner, or from scales graduated to 3″, $1\frac{1}{2}$″, and $\frac{3}{4}$″ to 1 ft. respectively.

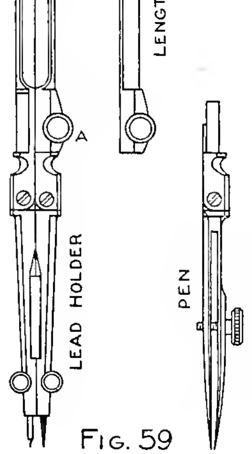


Fig. 59

In scales graduated to feet and inches the first unit, when large enough, is divided to represent inches and fractions. For example, in the scale of $1\frac{1}{2}$″ to 1 ft. the first unit is divided into 12 eighth-inch parts to represent inches, and each of these subdivided to represent halves and 4ths. Fig. 57 (b).

When 10ths, 20ths, 30ths, etc., of an inch are required, an engineer's or decimal scale is used. Any desired scale may be *drawn* by division of a line into the required proportional parts. See Art. 30.

For method of determining the size or scale to be used, see Art. 100(c).

(b) To set off a measurement (as say $2\frac{1}{4}$″). Apply the scale directly to the line, with the "0" division exactly at the end of the line, and the needle-point at the $2\frac{1}{4}$″ division. To set off, say 2 ft. and $2\frac{7}{8}$″, place the division representing $2\frac{7}{8}$″ at one end of the line and a pt. at that representing 2 ft.

Never transfer measurements from the scale with compasses or dividers. Successive measurements on a

line should, so far as possible, be set off without shifting the scale, so that an error in one distance may not affect all.

12. Protractor. A Protractor (Fig. 58) is a scale used in laying off and measuring ∠s. Its measuring edge is graduated to degrees and fractions (usually to half degrees), and the degrees numbered to read from 0 to 180° in both directions.

(a) To DRAW A LINE AT ANY GIVEN ANGLE WITH A GIVEN LINE (say 40°). Place the protractor with its 180° line 0-0 against the given line A-B and center C at the given vertex A. Now place a pt., D, at the 40° mark. Remove the protractor and draw A-D, the required line.

13. Compasses. The compass set (Fig. 59) is used for drawing circular curves. The needle should first be adjusted as follows:—Release clamp screw A, and remove the *lead holder*. Insert the *pen* in place of the latter, and clamp securely. Then set the needle so that the point of its shouldered end will be even with the pen point. Once set, the needle should not be changed. The lead only will need resetting, as it wears away.

(a) To PREPARE THE COMPASSES FOR PENCILING. Place a 4H compass lead, about 1″ long, in the holder, and taper it as directed for the ruling pencil. Refit the holder and adjust the lead to the length of the needle, with its edge so placed that a fine, even line will result when the compasses are revolved.

(b) To DRAW A CIRCLE. Open the compasses and adjust the legs at the joints so that both lead and needle will be at right ∠s to the paper while drawing. This is necessary to prevent the lead from wearing unevenly and the needle from digging into the paper. The puncture should be barely visible.

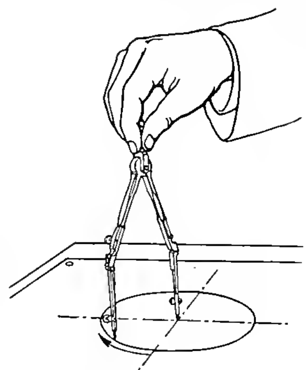


FIG. 60

Hold the compasses by the handle only, with thumb and first two fingers (see Fig. 60) and always revolve it around to the right (clockwise). Bearing lightly and evenly upon the lead point, draw the curve with one continuous motion, stopping exactly at the end of the revolution to avoid widening the line.

In drawing a ⊙ or arc of given rad., first set off the rad. upon a C.L., and, in placing the compass point at the center, steady the needle with a finger of the left hand.

Changes of rad. should be made, so far as possible, with the right hand only, and care taken not to enlarge the center.

(c) To INK CIRCLES AND CIRCULAR ARCS. Insert the pen and clamp it securely. Clean, fill, and set the pen, as directed in Art. 17(a). Open compasses to the rad. of the penciled curve and adjust the legs, as directed in (b). To give clean-cut lines, both blades must bear evenly upon the paper. The directions for penciling apply also to inking. Before placing the pen point upon the curve, the compasses should first be revolved over the line, in space, to make sure that the inked line will pass exactly through the desired pts. Errors caused by enlargement of centers may thus be avoided. Do not go over a line a second time.

(d) Lengthening Bar. When the rad. is too great to admit of placing the points ⊥ to the paper, the lead or pen leg should be extended by means of the lengthening bar. In this case, the needle leg may be steadied with the left hand and the drawing point moved with the other, care being taken not to change the rad.

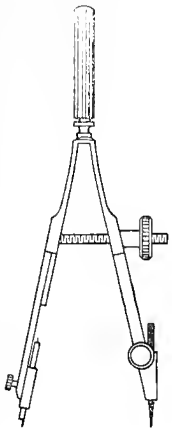


Fig. 61

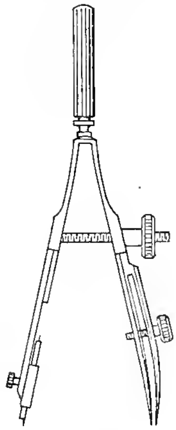


Fig 62

14. Bow Compasses. The *bow pencil* (Fig. 61) and *bow pen* (Fig. 62) are used for drawing small ⊙s and arcs for which the large compasses are not convenient. Do not use them for radii over $\frac{5}{8}''$. The directions for preparing and using the bow compasses are much the same as for the large compasses. The needle must project slightly beyond the pen or lead point, and the lead be tapered more nearly to a pt. To enable the points to be brought close together, the needle is generally flattened on its inner side. The rad. is adjusted by turning the thumb-nut on the connecting bar.

Before turning, spring the points together so that the wear of the screw thread may be lessened and the adjustment made more readily.

15. Dividers. The dividers or spacers (Fig. 63) are used for transferring measurements from one part of a drawing to another, and for setting off equal distances on a line when they cannot readily be laid off by means of the scale. Handle the dividers in the same general way as the compasses.

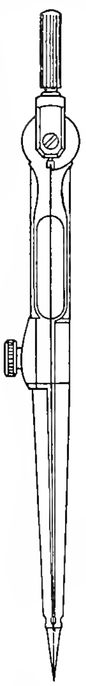


Fig. 63

In some dividers one leg is furnished with a hairspring and nut by means of which this leg may be moved for slight changes of adjustment.

(a) To divide a straight line or a circular curve into any number of equal parts (say 3). Open the dividers to a distance equal (by eye) to $\frac{1}{3}$ of the line to be divided, place one of its points upon the end of the line and revolve the dividers until the other point is exactly on the line. Proceed in this manner, revolving alternately in opposite directions, until the distance taken has been set off three times. Never remove both points at the same time. If the distance taken does not apply exactly it must be increased or diminished by an amount equal to $\frac{1}{3}$ of the difference, and the trial repeated until the line is equally divided. No pts. should be made visible until the divisions have been verified as correct.

16. Bow Dividers. Fig. 64. These are used for small distances, and in the same general manner as the large dividers. The points are adjusted as directed for bow compasses, Art. 14.

17. Ruling Pen. The ruling pen (Fig. 65) is used for inking all lines other than circular curves.

(a) To fill and clean the pen. Before filling the pen, moisten a folded end of the penwiper and draw it gently between the blades. When clean and dry bring the blades together at the point by means

of the thumb-screw; then holding the pen upright, not over the drawing, insert the ink between the blades with the filler. Do not fill above $\frac{1}{4}''$ from the point, otherwise the ink will flow out too freely. See also that there is no ink on the outside of the point, as this will widen the line, make it ragged, or cause a blot. Replace the stopper immediately to prevent the ink from thickening.

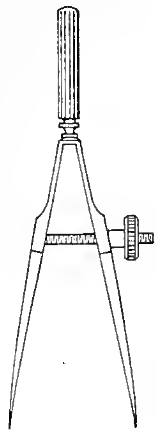


FIG. 64

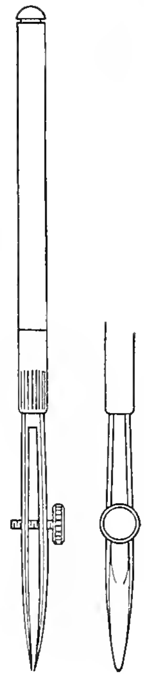


FIG. 65

Having filled the pen, set the blades to the required width of line. Always try the pen on a piece of waste paper before using it on the drawing. To insure its flowing freely, the amount of ink in the pen must be kept as nearly as possible the same. Avoid having to piece out a line. As the ink dries rapidly, the pen must be cleaned and refilled frequently. In doing this, it is not necessary to open the blades. The setting should remain unchanged until all lines of the same width are inked. If the pen fails to work, it should be sharpened by an experienced person. Never put the pen aside without carefully cleaning it.

(b) To RULE A LINE. Hold and steady the pen as directed for the pencil (Art. 9 (c)), the first finger resting on the flat side of the pen above the thumb-screw and the second against the edges of the blades as shown in Fig. 50.

Adjustments for width are made with thumb and second finger of the same hand.

Guard against getting the pen point too close to the ruling edge by placing the latter slightly away from the line, as shown. A slight downward pressure only should be necessary, but the points of both blades must bear evenly upon the paper to give a clean-cut line. Bear lightly against the ruling edge to prevent varying the width of the line. Always steady the hand, and move the pen from left to right as directed for penciling. Just before reaching the end of the line stop the arm movement and complete the line with a finger movement, then lift the pen immediately and move the ruling edge away from the line.

In ruling curves, turn the pen gradually so that the blades will not be at an $\angle$ with the ruling edge. Art. 18. Never use the ruling pen freehand.

18. Curve Rulers. These are used for ruling curves that cannot be drawn with the compasses. They are made in various shapes and sizes. Two of the most serviceable are shown in Figs. 66, 67.

(a) To RULE A CURVE, ABC. Fig. 67. First sketch the curve lightly with freehand pencil, through previously determined pts. Now find, by trial, a portion of the ruler which will fit as much of the curve as can be ruled conveniently at one time, as A-B, and true up that part by tracing over it with the ruling pencil.

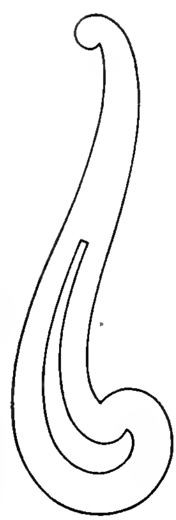


FIG. 66

Match succeeding parts in the same manner, making the edge fit over a portion of each preceding part to insure an even, unbroken line. The freehand penciling should not be omitted, as the tendency would be to make the ruled line curve out too much or too little. Having trued the line, rub the soft rubber lightly over it.

In inking the curve, use the ruling pen as described in Art. 17(b). In ruling curves symmetrical about one or more axes, as ellipses, helices, etc., the portion of the ruler used for one part should be noted and used for corresponding parts. Sharp turns at ends of axes should first be drawn by means of compasses, the centers being taken in the axes and care taken to use the proper rad. and length of arc.

(b) Non-circular curves may often be approximated throughout by tangent arcs. Thus, in inking the curve shown by the fine line in Fig. 68, beginning say at A, determine by trial the center and rad. of as much of an arc as will practically coincide with the curve. Ink this arc; then, changing the center and rad., ink the next portion; note that the centers must be on the line through the pt. of tangency.

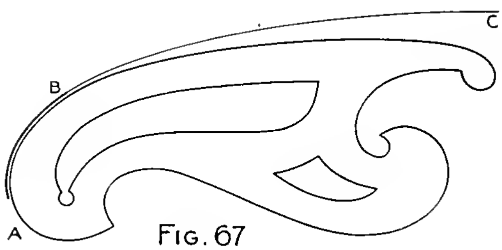


FIG. 67

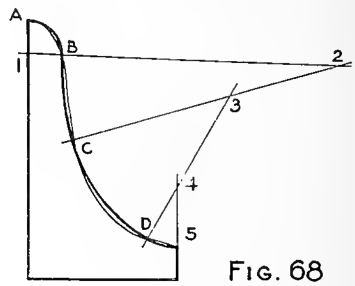


FIG. 68

19. Erasers. (a) The *soft rubber* is used for pencil erasing and paper cleaning. Keep paper as clean as possible from the start. (See Art. 5.) The softest rubber is liable to roughen the paper, making it difficult to keep clean and to obtain sharp lines. In removing a line, rub lengthwise. Avoid much pressure and always remove dust before proceeding with drawing. When a drawing is finished in ink, the eraser may, if necessary, be passed lightly over the entire surface, care being taken to avoid dulling the lines.

(b) The *hard rubber* is used for ink erasing. The part to be removed should first be allowed to dry. Care must be taken not to injure the surface. Never use a knife. If the surface is roughened by erasing, smooth it as well as possible with the finger nail. A thin card or piece of celluloid with narrow openings can be used to protect adjacent parts when erasing.

CHAPTER III

PENCILING AND FINISH RENDERING

20. Layout of the Sheet. (a) MARGIN LINES. To improve the general appearance of the drawing and to insure keeping all lines and figures a safe distance from the edges of the sheet, it is customary to rule *border lines* with uniform marginal spaces at top, bottom, and sides. See Fig. 69.

Assuming the paper to be 11″ x 15″, the required border 10″ x 13½″, and marginal spaces ½″, proceed to lay out the border and *trim lines* as follows: Having tacked the paper to the board (Art. 6) set off two pts. near the left edge, ½″ and 10½″ respectively, above the lower edge, Art. 11. Through these pts. draw light horizontals across the sheet, Art. 7. On the lower hor., set off a pt. ¼″ from the left edge; ½″ from this place a second; 13½″ from the second, a third; and ½″ from that a fourth. Through these pts., draw the 90° lines (verticals), Art. 8. Test distances between verts. at the top and hors. at the right with the scale.

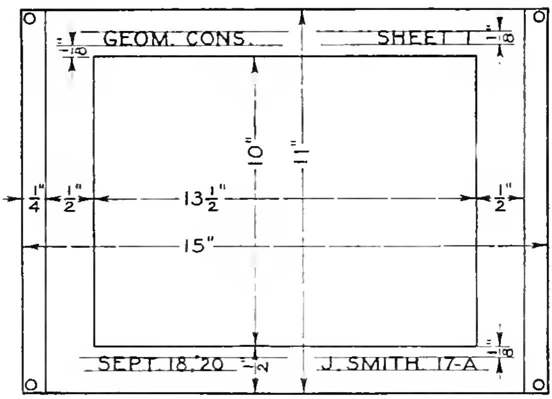


FIG. 69

When the sheet is completed and removed from the board, the ¼″ strips containing the tack holes are to be cut off, thus leaving the sheet 11″ x 14½″.

(b) LOCATION OF NAME, TITLE, ETC. On elementary drawings these may be lettered as shown. For titles, etc., on working drawings, see Art. 102. For instructions in lettering, see Art. 25.

21. Constructive Stage of the Drawing. All lines should be penciled first in uniform, fine full lines, as indicated in Fig. 209(a), (b), (c). Then, to avoid errors in the finishing stage (Art. 22), lines representing edges and outlines of the object should be gone over with a slightly firmer pressure, and the hidden parts

dashed as in Fig.(d). The general order of penciling different kinds of drawings is indicated in Art. 3.

To avoid the necessity of piecing out, make the lines first of indefinite length. Be sure that all measurements are set off upon definite lines and that lines intended to pass through particular pts. actually do so. No part of the penciling should be slighted. Inaccuracies can seldom be corrected in the process of finishing. Aim to do no erasing until the penciling is completed.

To secure greater accuracy and economy of time, similar operations should be grouped. Thus, draw all lines that can be ruled with the T-square and triangles in one position at the same time, and ||s of one set before commencing those of another. When using the scale or dividers, set off all distances possible at once. When using the compasses work the circular curves in the same way, drawing those having the same rad. at one setting of the instrument, etc. As st. lines can be drawn tangent to curves more accurately than the reverse, pencil the curves first whenever possible.

To enable the method of procedure to be readily followed, all lines used in making the drawing should be left upon the sheet until it has been approved.

22. Finishing Stage of the Drawing. For greater distinctness and permanence the drawing is usually lined-in or finished with ink, either by going over the lines on the original or by making a tracing as in Art. 106. Drawings not intended for continued use or of which no copies are needed are often finished in pencil.

Do not commence the finishing stage until the constructive stage is completed and approved. See that the drawing surface is free from dust.

(a) Inking. Be careful to make sharp, even lines, and see that all lines begin and end exactly where it is intended that they should. To prevent lines running together at their intersection, see that the first is thoroughly dry before inking the second. Do not use a blotter.

(b) Finishing in Pencil. If the drawing is to be finished in pencil, the aim should be to secure as nearly as possible the accuracy and distinctness of an inked drawing. The medium pencil should be used, at least for strengthening object lines. In finishing dashed lines it is not necessary to erase lines of the constructive stage between dashes as they will not be prominent if the finish lines are properly emphasized.

(c) Line Conventions. The different purposes of the lines of the drawing are indicated by varying their character, width, or color. The conventions shown in Fig. 70 are commonly used on drawings finished wholly in black ink or in pencil, for the purposes stated below. They are suitable in width, length of dash, etc., for ordinary drawings.

A—*Visible lines of objects in all required views* and edges in developments.*

B—*Hidden lines of objects in all required views.* As a rule end dashes should touch the limiting lines.

C—*Visible lines of objects in auxiliary views used in determining required views.* When aux. views show visible lines only, they may be finished as construction lines.

*When shadow or shade lines are used, shade the curved edges as each is lined-in. (See Art. 23(c).) St. shadow lines are left in pencil until all but the border is finished.

D—*Hidden lines of objects in auxiliary views used in determining required views.*

E—*Traces of projection, section, and base planes; center lines, and axes.* Dashes of section traces, center lines and axes should extend about $\frac{3}{8}''$ beyond the view or part on which they are drawn.

F—*Construction (working) lines required to show method of construction; projectors, and extension lines.* Dashes of extension lines should not touch lines of views, and should extend about $\frac{1}{16}''$ beyond arrowheads of dimension lines.

G—*Dimension lines, and pointers.*

H—*Break lines.* Same as edges, etc., but should be drawn freehand.

I—*Arrowheads, figures, notes, titles, etc.* These should be penciled freehand, and in inked drawings always finished in black. See Fig. 74.

J—*Section lining.* Same as C, or as in Fig. 187.

K—*Line shading.* As in Art. 24.

L—*Straight shadow and shade lines of all required views, and border lines.*

Red ink. In inked drawings, the use of full red lines for all lines under C, E, F, and G, and dashed red for those under D is more economical of time and makes the required views more prominent.

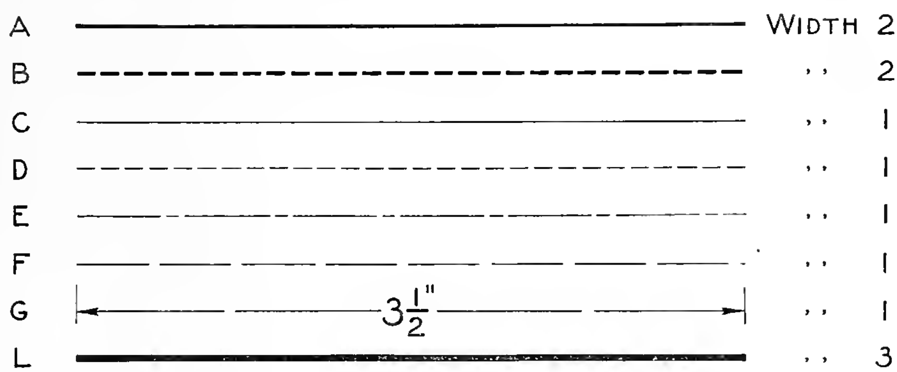


FIG. 70

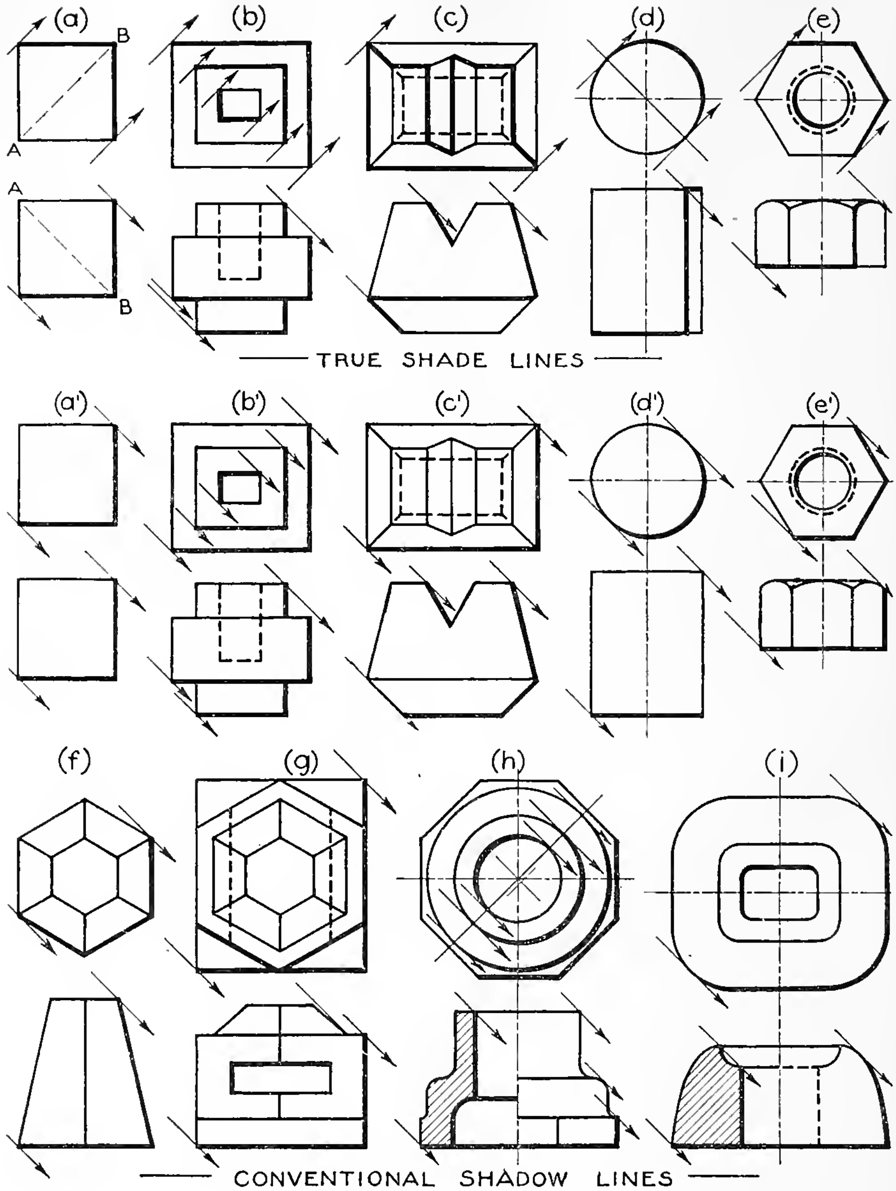
(d) ORDER OF FINISHING. It is desirable to complete all lines and parts of similar character before proceeding with those of another, in the general order indicated in Art.(c), in observing which, similar operations should be grouped as in the following:—

Circles and arcs, beginning with the smallest; *non-circular curves; horizontals,* beginning with those at the top; *verticals,* beginning with those at the left; *obliques,* beginning with those obtainable by T-square and triangle combinations.

Do not use a triangle alone, unless necessary.

In finishing break lines, arrowheads, figures, and notes, etc., work from upper part of sheet downward.

23. Shadow Lining. In practical drawings, visible edges and outlines of objects are generally indicated by full lines of uniform width. It is sometimes desirable, however, to finish certain lines wider than the others for the purpose of giving an appearance of relief to the drawing and to indicate the relative positions of the surfaces more clearly.



(a)
B
A
A
B
(b)
(c)
(d)
(e)
TRUE SHADE LINES
(a')
(b')
(c')
(d')
(e')
(f)
(g)
(h)
(i)
CONVENTIONAL SHADOW LINES

FIG. 71

(a) If a cube placed as in Fig. 71(a) be lighted by || rays coming over the left shoulder, in the direction of diagonal A-B, it is evident that the upper, left, and front faces will be in the light, the others in the shade.

Lines separating light from dark surfaces are called *shade lines.* The visible shade lines of the cube will, therefore, be the lower and right lines in the front view, and the upper and right lines in the top view, and may be indicated by broad lines as shown.

Assuming the same direction for the light, the visible shade lines in all rectangular objects and parts, whose axes are || or $\perp$ to the planes of the views, would have the same general locations as in the cube. In such cases the shade lines can usually be determined by eye. The determination of the actual shade lines in all cases, however, would involve considerable time and labor, and their locations would frequently be such as to complicate the drawing rather than aid in explaining the form of the object; hence it is customary to disregard the actual shades and shadows and to apply the broad lines in such manner that they will indicate edges separating visible from hidden surfaces only, and so as to produce an effect of narrow shadows cast by the object.

It is convenient to regard these lines as *shadow lines* rather than as shade lines.

To further simplify the application, most draftsmen shade or shadow-line all views the same as the front.

The aid given by such lines in reading a drawing will be apparent from the figures.

The directions for this conventional method may be stated as follows:—

(b) Shadow-line the lower and right lines of intersection between visible and hidden surfaces in all views, regardless of the actual shades or shadows of the object. This includes both sharp and slightly rounded edges. Lines not representing such edges are generally shadow-lined only when surfaces extend back from them at right $\angle$s to the plane of the drawing, in order to indicate more clearly that they do not represent edges. A sectional view is generally shadow-lined just as if the portion shown were complete. Lines representing broken surfaces are preferably not shadow-lined. Never shadow-line the line of intersection between visible surfaces, nor dashed lines.

(c) To SHADOW-LINE A DRAWING. In determining the shadow lines remember that the rays of light will be at 45° down to the right in all views and that all views are shadow-lined in the same manner. Limiting rays may be penciled as shown. Each edge to be shadow-lined should be indicated by a mark upon the line before inking is begun. Drawings are never shadow-lined in pencil.

Straight Lines. A st. shadow line should be ruled the required width (3) at one stroke of the ruling pen, and its width added on the outside of the pencil line.

Circular Curves. First ink the curve in the usual manner (width 2). Then taking a second center below and to the right of the first, on a 45° line, at a distance equal to width 3 and without change of rad. or setting of pen, draw an arc on the outside or inside of the first curve according to the required location of the shadow portion. (See Fig. 71(h).) If an uninked portion remains between the arcs, spring the instrument slightly to fill it in.

Irregular Curves. First ink the widest portion; then with the ruling pen set to width 2, blend this carefully into the rest of the curve.

24. Line Shading. This is a conventional method of producing an effect of light and shade, corresponding to that upon the object itself by means of lines, usually of graded widths and spacing. Fig. 72. It is used on drawings intended for illustrative purposes and in cases where it is necessary to indicate the direction of certain surfaces more clearly than would be possible by the mere outline or by shadow lines.

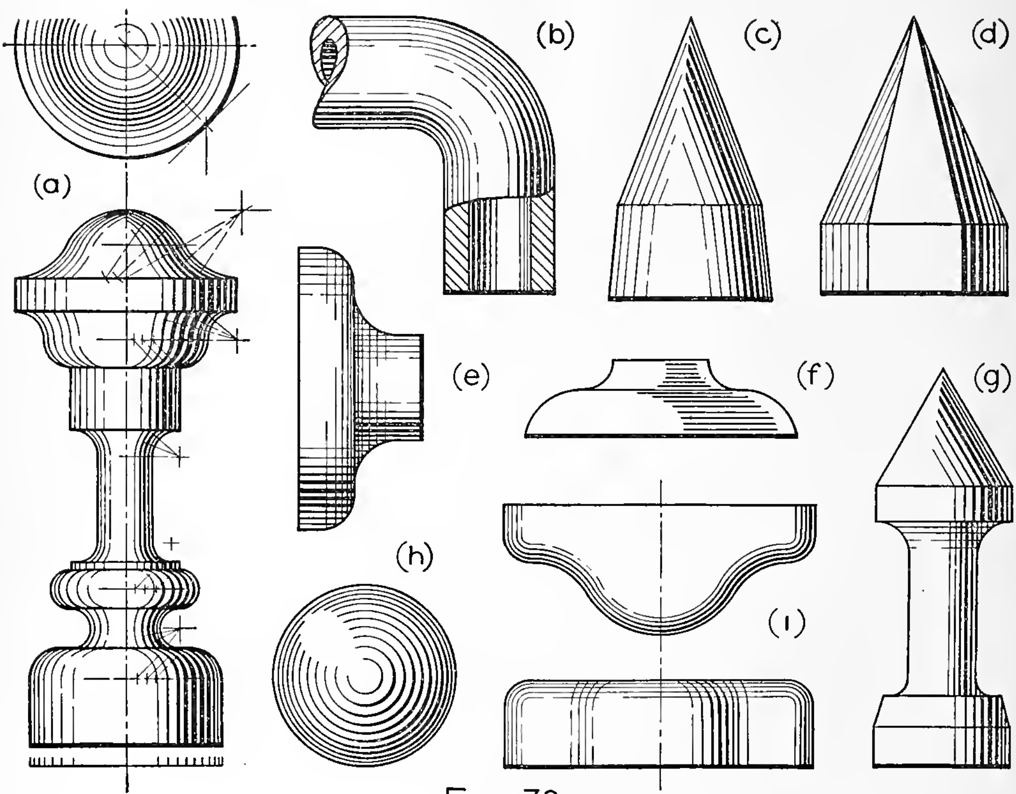


FIG 72

(a) The direction of the light is assumed as for shadow-lining (Art. 23); the same for all views. The right and lower sides are, therefore, the dark sides on convex surfaces and the left and upper on concave surfaces. In regular curved surfaces the darkest portion is about $\frac{3}{4}$ of the rad. from the center. It may be accurately determined as shown in top view of Fig.(a). The spacing may be indicated in pencil, as below Fig.(a). Shade first the dark portion, beginning at about $\frac{1}{4}$ of the rad. from the center. Use fine lines only on the light side, somewhat farther apart than on the dark, and stop at about $\frac{1}{2}$ of the rad. from the center. On small parts shade dark side only. (See Fig.(g).) Figs. (a) and (i)

illustrate methods of shading fillets, beads, etc., on large drawings; Figs.(e), (f), (g), for small drawings. The shading of conic surfaces by || lines, as shown, is less difficult and generally more satisfactory than by radial lines. When desirable to shade plane surfaces, the method in Fig.(d) may be used.

25. Lettering. The names, titles, notes, and dimensions required on drawings should be carefully lettered in even, well-proportioned, and well-spaced characters.

The styles shown in Fig. 73 are those most generally used.

The inclined Gothic differs from the vertical only in the slant. The vertical is sometimes chosen for titles and headings, and the inclined for notes and dimensions. A uniform style for all lettering is more common.

The capitals may be used with or without lower-case (small) letters, or with small capitals in place of the latter. Titles and headings are usually more satisfactory if all capitals are used, while notes are more easily read if composed of capitals and lower-case letters.

(a) Proportions. The character, proportions, and relations of the elements composing the letters and numerals should be carefully noted and fixed in mind. Examination of the vertical Gothic will show that W is the widest character, M next, and A, V, and 4 next; that I, J, and 1 are narrowest; and that the others are nearly equal in width to letter O. For general purposes this width should be from $\frac{3}{4}$ to $\frac{7}{8}$ of the height. These variations are designed to overcome the appearance of inequality which would result if all were made equal when used in words. For like reason A is extended slightly above the other letters and V below. The curves of C, G, J, O, Q, S, U, 2, 3, 5, 6, 8, and 9 also extend slightly beyond. To avoid the effect of top-heaviness the upper part of B, C, E, G, K, R, S, X, Z, 2, 3, 5, 6, and 8 is slightly narrower than the lower, and certain parts in B, E, F, H, R, S, X, 3, 5, 6, and 8 come slightly above the middle, while in A, G, K, P, Y, 4, and 9, they come below. All curves are elliptic.

In practice the variations in height and width noted above should be estimated by eye.

The body of the lower-case letters should be $\frac{2}{3}$ or $\frac{3}{4}$ of the initial capitals.

The sizes of letters and numerals generally suitable are indicated in Fig. 74.

(b) Spacing. The spaces between letters vary in shape with each different combination. In order to make these spaces appear equal in size and thus avoid the effect of crowding or isolating letters, it is necessary to increase the spaces in certain cases and decrease them in others. Thus, considering the vertical capitals, the spaces of I should be considerably greater than of other letters, especially when parts of adjoining letters are || to it. In letters whose sides are curved as in O, C, D, etc., it is generally necessary to decrease the space. This is also true of letters having oblique sides as in A, V, etc., and letters having a greater space at one or both sides as in L, J, P, T, etc.

The simplest method of obtaining good spacing is to sketch the words lightly and study the effect.

The space between words should be about $1\frac{1}{2}$ times the width of letter O; that between sentences in line about three O's; and that between || lines of lettering about equal to the height of the shortest letters in either.

(c) PENCILING. In penciling titles, etc., and notes, rule only the hor. guide lines, and a few vert. or slant lines to preserve the correct positions. For method of planning a title see Art. 102(c). In dimensioning drawings estimate the heights of the numerals by eye.

Draw all characters freehand, using a fairly sharp pencil point. Art. 9.

Before lettering a drawing, the style to be used should be practiced until it can be done reasonably well. Unless otherwise directed, begin with the vertical capitals, observing the order given by the numbers below them; then practice word-combinations; then the figures.

Place Fig. 73 close to the work and analyze each character. A convenient order for drawing the strokes is indicated by the arrows. To determine the proper proportions and spacing, first point the forms and sketch lightly the main lines.

Bear in mind that the value of the practice is in the carefulness and not in the amount. Do not mix the styles.

(d) INKING. Use the medium-point writing pen for small letters and figures, and the coarse pen for large letters, etc. The width of the lines should be uniform and obtained at one stroke.

Observe number, order, and direction of strokes as in penciling.

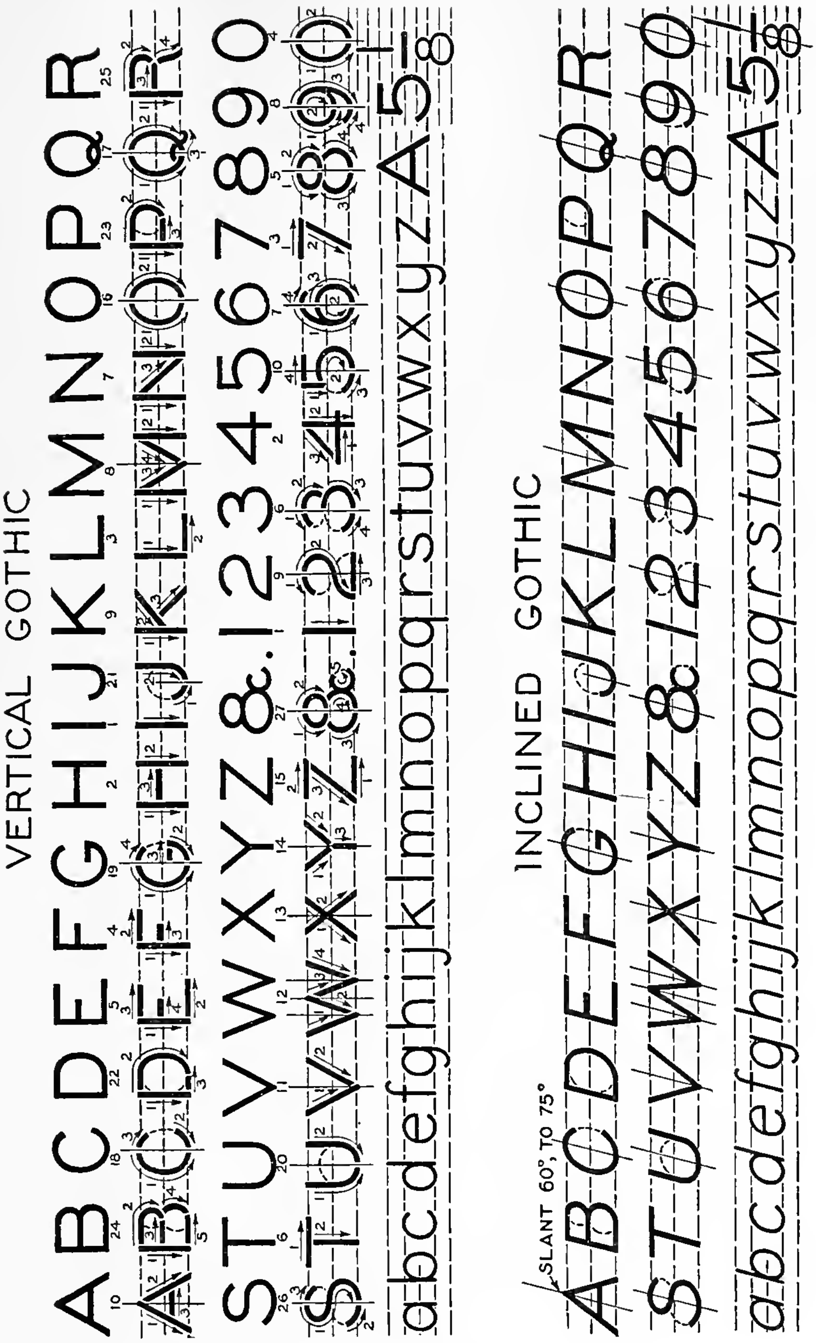

VERTICAL GOTHIC
ABCDEFGHIJKLMNOPQR
STUVWXYZ&1234567890
abcdefghijklmnopqrstuvwxyzA5 1/8
INCLINED GOTHIC
SLANT 60°, TO 75°
ABCDEFGHIJKLMNOPQR
STUVWXYZ&1234567890
abcdefghijklmnopqrstuvwxyzA5 1/8

FIG. 73

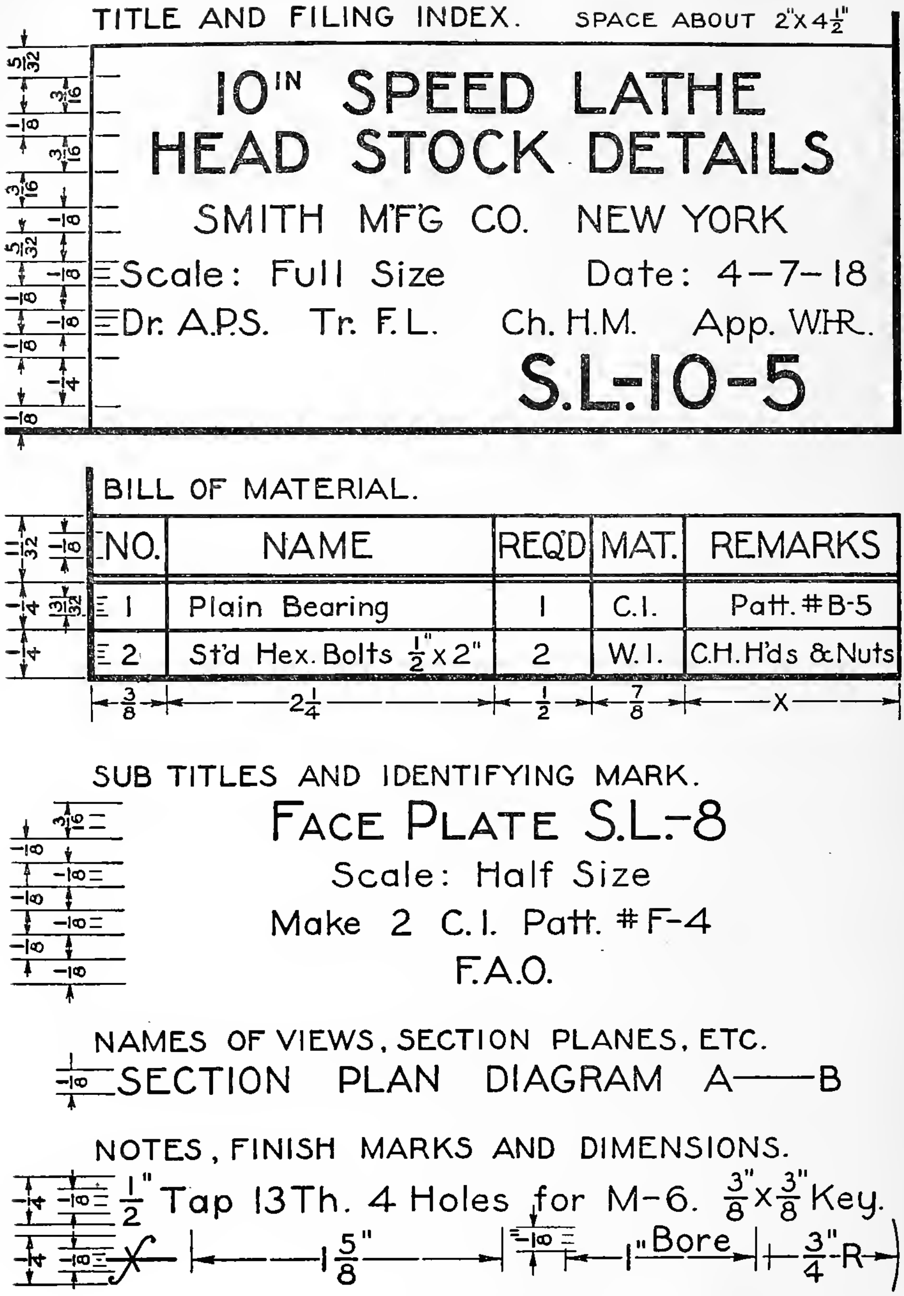

TITLE AND FILING INDEX.
SPACE ABOUT 2"X4½"
10IN SPEED LATHE
HEAD STOCK DETAILS
SMITH M'F'G CO. NEW YORK
Scale: Full Size
Date: 4-7-18
Dr. A.P.S. Tr. F.L. Ch. H.M. App. W.H.R.
S.L.-10-5
BILL OF MATERIAL.
NO.
NAME
REQ'D
MAT.
REMARKS
1
Plain Bearing
1
C.I.
Patt. #B-5
2
St'd Hex. Bolts ½" x 2"
2
W.I.
C.H.H'ds & Nuts
SUB TITLES AND IDENTIFYING MARK.
FACE PLATE S.L.-8
Scale: Half Size
Make 2 C.I. Patt. #F-4
F.A.O.
NAMES OF VIEWS, SECTION PLANES, ETC.
SECTION PLAN DIAGRAM A——B
NOTES, FINISH MARKS AND DIMENSIONS.
½" Tap 13Th. 4 Holes for M-6. ⅜"x⅜" Key.
1⅝"
1" Bore
¾" R

FIG. 74

CHAPTER IV

GEOMETRIC CONSTRUCTION

26. Geometric and Practical Methods. The accurate execution of the views and diagrams by which the lines and surfaces of an object are represented involves the graphic solution of various plane problems such as the division of lines and the construction of perpendiculars, parallels, polygons, etc.

In geometry (Art. 2) these solutions are obtained by the orderly application of geometric principles, which require the use of the compasses and a straightedge only in drawing the necessary working or construction lines.

While it is frequently necessary in practical drafting to obtain the solution by a geometric method, the draftsman is generally enabled to shorten the constructive process or to obtain a direct solution by means of the T-square, triangles, dividers, etc.

The constructions explained in this Chap. are those most commonly applied not only in drafting, but in the laying out of the actual lines and surfaces of objects by the workman.

The geometric method is that first given. Where a practical method (P. M.) is not also given, the geometric method would ordinarily be used.

27. To bisect a straight line, A-B, or a circular arc, A4B. Fig. 75. With A and B as centers and any rad. describe arcs intersecting in pts. 1 and 2. Through 1 and 2 draw a st. line, which will be ⊥ to A-B and bisect it at 3, and the arc A4B at 4.

Note 1.—Every pt. in the ⊥ bisector 1-2 is equidistant from A and B; hence a different rad. may be taken for each of its determining pts. 1 and 2, or both located upon the same side of A-B.

Note 2.—The ⊥ bisector of a chord, if extended, will pass through the center, 5, of the ⊙ of which the arc A4B is a part, and will bisect the ⊙, also the ∠ A5B of which the arc A-B is the measure.

Note 3.—The method of drawing a ⊙ or an arc of given rad. through two given pts., or upon a given chord, is evident.

P. M. Obtain division with the dividers, Art. 15 (a).

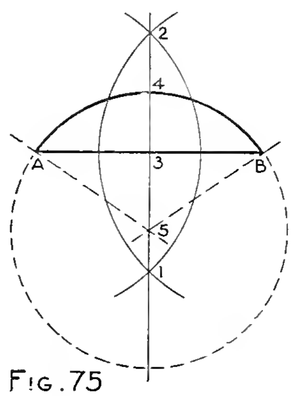


FIG. 75

28. To bisect an angle, CAB. Fig. 76. With any rad. locate pts. 1 and 2 upon the sides, equidistant from vertex A. With 1 and 2 as centers, any rad., locate an equidistant pt. 3. Draw 3-A, the bisector of the ∠.

Note.—When the vertex, A, is not usable, draw ||s to the given sides (see Art. 36), obtaining A′, and bisect ∠ C′A′B′.

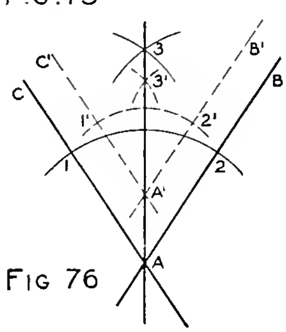


FIG 76

29. To construct an angle equal to a given angle, CAB. Fig. 77. Draw an indefinite line A′-B′. With A as center and any rad., draw arc C-B to cut the sides of the given ∠. With A′ as center, same rad., draw an indefinite arc C′-B′. With the chord of C-B as rad. and center B′, cut C′-B′, at C′. Draw A′-C′ completing the required ∠.

30. To divide a straight line, A-B, into any number of equal parts (say 5). Fig. 78. Draw A-4 at any ∠ with A-B. Draw B-1′ at the same ∠, Art. 29. From A and B set off any distance upon A-4 and B-1′, as many times as the required number of divisions on A-B, less one. Draw 4-4′, 3-3′, etc., which will divide A-B as required.

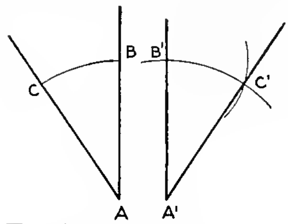


FIG. 77

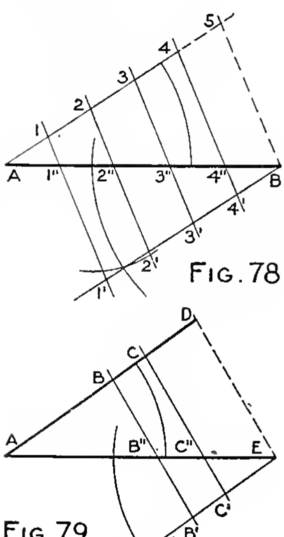


FIG. 78

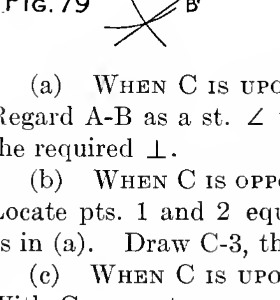


FIG. 79

SECOND METHOD. Set off five equal distances upon A-5 from A, and draw ||s to 5-B by making ∠s at 4, 3, 2, and 1 equal to ∠ A5B.

Note.—Any line, as 1-1″, || to one side, 5-B, of a △, divides the other two sides, A-B and A-5, proportionally. Thus the ratio of A-1″ to 1″-B equals the ratio of A-1 to 1-5; also A-1″ is to A-1 as A-B is to A-5.

P. M. Draw A-5 at any ∠ with A-B and from A set off five equal distances upon it. Draw ||s to 5-B through 4, 3, 2 and 1 by Art. 8(c), dividing A-B as required; or obtain divisions by Art. 15(a).

31. To divide a straight line, A-E, into parts proportional to those of a given divided line, A-D. Fig. 79. The method is evident from Art. 30.

32. To lay off the length of a given circular curve upon a straight line. There is no exact method. Divide the given curve into short arcs, not necessarily equal, whose chords will closely approximate the lengths of the subtended arcs. Lay off these chords successively upon the st. line.

Note.—The length of the circumference of a ⊙ is 3.1416 times the diam.; hence it may be computed and the nearest fraction taken from a table of decimal equivalents.

33. To lay off the length of a given straight line upon an arc. The method is evident from Art. 32.

34. To draw a perpendicular to a line, A-B, from or through a given point C.

(a) WHEN C IS UPON A-B, AT OR NEAR THE MIDDLE OF THE LINE. Fig. 80. Regard A-B as a st. ∠ with vertex at C and proceed as in Art. 28. C-3 will be the required ⊥.

(b) WHEN C IS OPPOSITE OR NEARLY OPPOSITE THE MIDDLE OF A-B. Fig. 81. Locate pts. 1 and 2 equidistant from C, and pt. 3 equidistant from 1 and 2, as in (a). Draw C-3, the required ⊥.

(c) WHEN C IS UPON A-B AND AT OR NEAR THE END OF THE LINE. Fig. 82. With C as center, any rad., draw an arc cutting A-B at 1. With 1 as center,

same rad., cut this arc at 2. With 2 as center, same rad., draw an arc above C. Through 1 and 2 draw a st. line to cut the last arc at 3. Draw C-3, the required ⊥.

Note 1.—The dotted arcs suggest another method of locating pt. 3.

Note 2.—Any ∠, as 1C3, inscribed in a semicircle, is a right ∠.

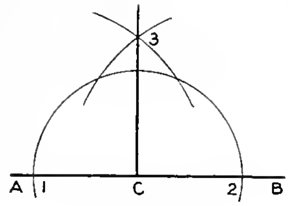


FIG 80

SECOND METHOD. Fig. 82. Assume any pt. 2, not upon A-B, as center, and with rad. 2-C, draw an arc cutting A-B at 1. Through 1 and 2 draw a st. line to cut this arc at 3. Draw C-3.

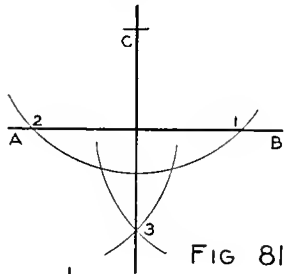


FIG 81

(d) WHEN C IS OPPOSITE OR NEARLY OPPOSITE THE END OF A-B. Fig. 83. From C draw any line C-1, intersecting A-B obliquely. Bisect C-1 at 2. With 2 as center, rad. 2-C, cut A-B at 3. Draw 3-C, the required ⊥.

Note.—Compare with second method of preceding.

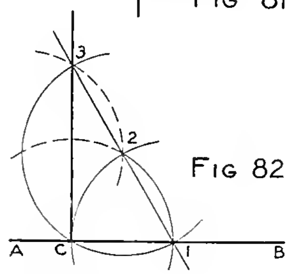


FIG 82

SECOND METHOD. Fig. 83. From any two pts. on A-B, as 1 and A, and radii 1-C and A-C, describe arcs to intersect at 4. Draw C-4.

P. M. For all cases: Obtain the ⊥ by Art. 8(d).

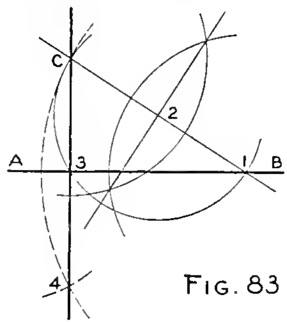


FIG. 83

35. To draw a line at an angle of any given magnitude in a quadrant, with a given line, A-B, at A. Fig. 84.

(a) 45°. Draw A-1 at 90° with A-B by Art. 34(c). Bisect ∠ 1AB by Art. 28; then A-3 will make an ∠ of 45° with A-B. See also Note 1.

(b) 60°. With A as center, any rad., draw an arc cutting A-B at 2. With 2 as center, same rad., cut this arc at 4. Draw A-4, which will make an ∠ of 60° with A-B.

(c) 30°. Determine a 60° ∠ 4AB as in (b) and bisect it; then line A-5 will be at 30° with A-B. See also Note 1.

(d) 15°. Determine a 30° ∠ 5AB, as in (c) and bisect it; then A-6 will be at 15° with A-B.

(e) 75°. Determine a 90° ∠ 1AB as in (a) and a 60° ∠ 4AB as in (b). Bisect the 30° ∠ 1A4 and A-7 will be at 75° with A B.

(f) By trisecting the 15° arcs of quadrant 1-2 and dividing the 5° arcs thus obtained into degrees, by trial (Art. 15(a)), a line at any intermediate degree may be determined. Lines at ∠s involving fractions of degrees may be determined by the same general methods.

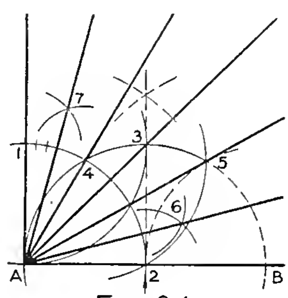


FIG. 84

Note 1.—The dotted lines suggest another method of locating pts. 3 and 5.

Note 2.—Observe that the rad. of a ⊙ is equal to a chord of $\frac{1}{6}$ of its circumference

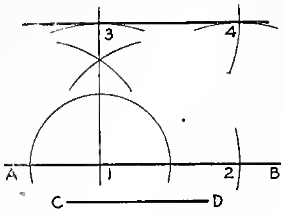


Fig 85

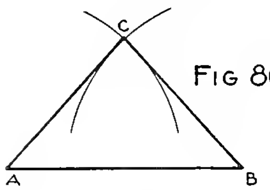


Fig 86

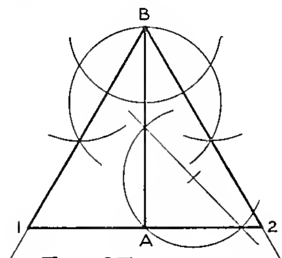


Fig 87

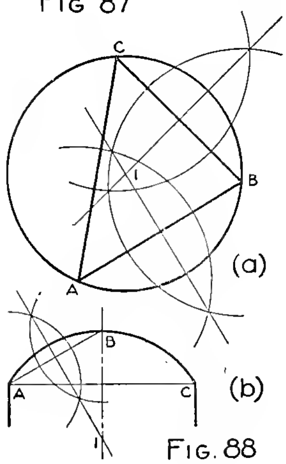


Fig. 88

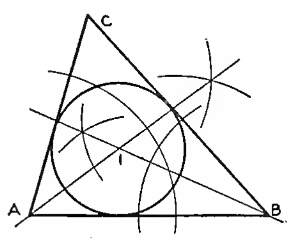


Fig. 89

P. M. Lines at 90°, 45°, 60°, 30°, 15°, and 75° may be obtained by Art. 8(d). For lines at intermediate degrees see (f). The protractor (Art. 12) may be used for all cases not involving fractions other than $\frac{1}{2}$°.

36. To draw a parallel to a given straight line, A-B.

(a) At a given distance, C-D, from A-B. Fig. 85. With any two pts., 1 and 2, on A-B as centers and C-D as rad., describe arcs on the same side of A-B. At 1 draw a ⊥ to A-B, cutting the arc from 1 at 3. With 3 as center and rad. 1-2, cut the arc from 2 at 4. Draw 3-4, the required ||.

P. M. At any pt., 1, on A-B draw a ⊥ 1-3 (Art. 8(d)), and make 1-3 equal to C-D. Through 3 draw 3-4 || to A-B. Art. 8(c).

(b) Through a given point 3. Fig. 85. Locate any two pts., 1 and 2, on A-B. With 1-3 as rad. and pt. 2 as center describe an arc on the same side of A-B as pt. 3. With 3 as center and rad. 1-2 cut the last arc at 4. Draw the required parallel 3-4.

P. M. Draw 3-4 || to A-B by Art. 8(c).

37. To construct a triangle.

(a) When the sides are given. Fig. 86. Make A-B equal to one of the given sides. With A and B as centers and radii equal to the second and third sides draw arcs intersecting at C. Draw A-C and B-C to complete the △.

P. M. When the given sides are equal draw the second and third at 60° with the first by Art. 8(d).

(b) When a side A-B, and the angles at A and B, are given. Fig. 86. Make the side A-B and ∠s CAB and ABC equal to the given side and ∠s, and extend A-C and B-C to meet at C.

(c) When a side A-B, the angle at B, and the angle opposite A-B, are given. Fig. 86. Find the angular magnitude at A by subtracting the sum of the known ∠s at B and C from 180° and proceed as in (b). See Fig. 20.

38. To construct an isosceles triangle when the base, A-B, and vertex angle, ACB, are given. Fig. 86. Find the angular magnitudes at A and B by subtracting the known ∠ from 180° and bisecting the remainder; then proceed as in Art. 37(b).

39. To construct an equilateral triangle when the altitude, A-B, is given. Fig. 87. Draw B-1 and B-2 at 30° with A-B, Art. 35(c). Draw 1-2 ⊥ to A-B, Art. 34(c).

P. M. Draw B-1 and B-2 at 30° with A-B, Art. 8(d). By same Art. draw 1-2 ⊥ to A-B.

40. To circumscribe a circle about a given triangle, ABC. Fig. 88(a). Draw the ⊥ bisectors of either two sides, as A-B and B-C (Art. 27) to intersect at 1; pt. 1, being equidistant from A, B, and C, will be the center of the required ⊙.

Note 1.—The center of any ⊙ is at the intersection of the ⊥ bisectors of any two of its non-parallel chords.

Note 2.—The method of drawing a ⊙ through any three pts., not in the same st. line, is evident.

41. To inscribe a circle within a given triangle, ABC. Fig. 89. Draw the bisectors of either two of the ∠s, as CAB and ABC (Art. 28) to intersect at 1, the center of the required ⊙. The ⊥ distance from the center to any side is its rad.

42. To inscribe an equilateral triangle within a circle. Fig. 90. Draw a diam. 1-2. From either end, 2, draw chords at 30° with 1-2 by Art. 35(c). Draw 3-4 to complete the △.

P. M. Draw diam. 1-2. Draw sides 2-3 and 2-4 at 30° with 1-2 by Art. 8(d) and join 3 and 4.

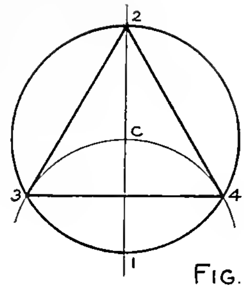


FIG. 90

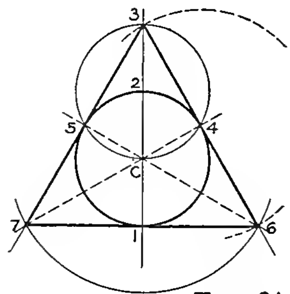


FIG. 91

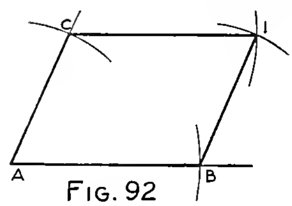


FIG. 92

43. To circumscribe an equilateral triangle about a circle. Fig. 91. Draw a diam. 1-2. From 2, with a rad. equal to that of the given ⊙, cut the diam. extended at 3, and the given ⊙ at 4 and 5. Draw 3-4 and 3-5. With C as center, rad. C-3, cut 3-4 and 3-5 extended at 6 and 7. Draw 7-6 to complete the △.

P. M. Draw 7-6 tangent to the ⊙ by eye; through center C draw 7-4 and 5-6 at 30° with 7-6, Art. 8(d). By same Art. draw 7-3 and 3-6 at 60° with 7-6.

44. To construct a parallelogram when two sides, A-B and A-C, and the included angle, CAB, are given. Fig. 92. Make the sides A-B and A-C and the included ∠ CAB equal to the given sides and ∠. Draw C-1 || and equal to A-B by Art. 36(b) and draw B-1 to complete the parallelogram.

P. M. Make ∠ CAB equal to the given ∠ by Art. 29. Make A-B and A-C equal to the given sides. Draw the || sides by Art. 8(c).

45. To construct a square on a given side, A-B. No figure. Draw a second side A-C ⊥ to A-B, Art. 34(c). Draw C-1 || to A-B, and B-1 || to A-C, by Art. 36(b), to complete the square.

P. M. Draw A-C and B-1 at 90° with A-B, and A-1 at 45°, by Art. 8(d). Draw C-1 || to A-B by Art. 8(c).

46. To inscribe a square within a circle. Fig. 93. Draw a diam. 1-2. From 1 and 2 draw chords at 45° with 1-2 (Art. 35(a)) to form the square.

P. M. Draw ⊥ diams. 1-2 and 3-4. At 45° with these, draw sides 1-4, 3-2, etc., Art. 8(d).

47. To construct a square on a given diagonal, 1-2. Fig. 93. The method is evident from Art. 46.

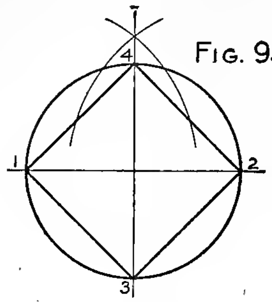


FIG. 93

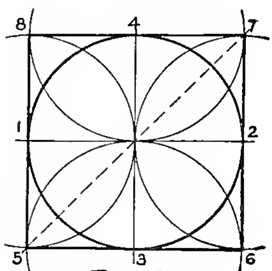


FIG. 94

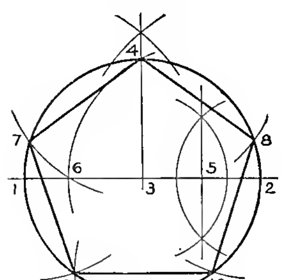


FIG. 95

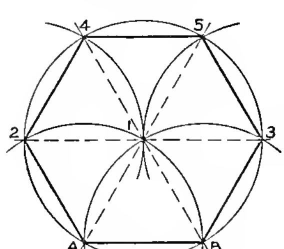


FIG. 96

48. To circumscribe a square about a circle. Fig. 94. Draw ⊥ diams. 1-2 and 3-4. Through 1, 2, 3, and 4 draw ||s to these diams. (see Art. 36(a)), forming the required square.

P. M. Draw || tangents 8-7 and 5-6, Art. 8(c). Through the center and at 45° with these draw 5-7, Art. 8(d). By same Art. draw tangents ⊥ to the first two.

49. To inscribe a regular pentagon within a circle. Fig. 95. Draw a diam. 1-2 and a ⊥ rad. 3-4. Bisect 3-2 at 5. From 5, rad. 5-4, cut the diam. 1-2 at 6. The chord of 4-6 is equal to one side of the required pentagon. Hence, with 4 as center, rad. 4-6, cut the circumference at 7 and 8. With 7 and 8 as centers, cut it again at 9 and 10. Draw chords 7-4, 4-8, etc., to form the pentagon.

P. M. Divide the circumference into five equal parts by trial (Art. 15 (a)), and connect the pts.

50. To construct a regular hexagon on a given side, A-B. Fig. 96. With A and B as centers, rad. A-B, draw arcs intersecting at 1. With 1 as center, same rad., describe a ⊙ cutting the first arcs at 2 and 3. With 2 and 3 as centers, same rad., cut the circumference at 4 and 5. Draw chords 2-4, B-3, etc., to complete the hexagon. See Art. 35, Note 2.

P. M. Draw A-5 and 4-B at 60° with A-B, Art. 8(d). Through their intersection, 1, draw 2-3 parallel to A-B, Art. 8(c). Draw B-3, 2-A, 2-4, and 5-3 at 60° with 2-3, and 4-5 parallel to 2-3.

51. To inscribe a regular hexagon within a circle. Fig. 97. Draw a diam. 1-2. Draw chords 1-3, 5-2, 6-2, and 1-4 at 60° with 1-2, Art. 35(b). Draw 3-6 and 4-5 to complete the hexagon.

P. M. Draw diam. 1-2. Draw diam. 4-6 and sides 1-3, 5-2, 6-2, and 1-4 at 60° with 1-2, Art. 8(d). Draw sides 3-6 and 4-5 || to 1-2, Art. 8(c).

52. To construct a regular hexagon on a given long diagonal, 1-2. The method is evident from Art. 51.

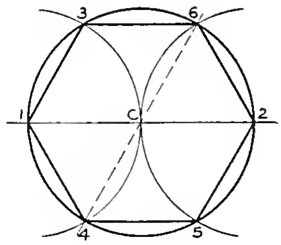


FIG. 97

53. To inscribe a regular octagon within a circle. Fig. 98. Draw ⊥ diams. 1-2 and 3-4. Bisect the 90° ∠s by Art. 28. Draw chords 1-5, 5-4, etc., to form the octagon.

P. M. Draw ⊥ diams. 1-2 and 3-4, and diams. 5-6 and 7-8 at 45° with these, Art. 8(d). Draw sides 1-5, 5-4, etc.

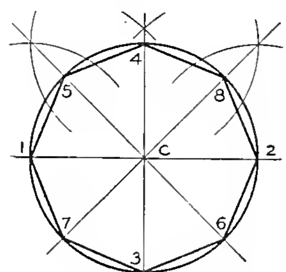


FIG. 98

54. To circumscribe a regular octagon about a circle. Fig. 99. Circumscribe a square about the ⊙, Art. 48. With pts. 1, 2, 3, and 4 as centers, rad. 1-C, cut the sides at S, T, U, V, etc. Join S, X, T, W, etc., to complete the octagon.

P. M. Draw || tangents 4-3 and 1-2. ⊥ to these draw 1-2 and 2-3. At 45° with these draw S-X, T-W, Y-V, and Z-U.

55. To construct any regular polygon. GENERAL METHODS.

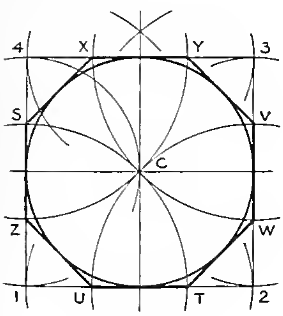


FIG. 99

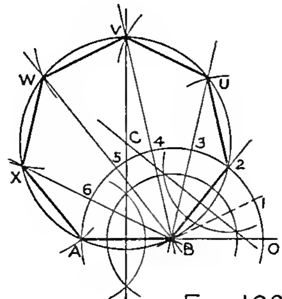


FIG. 100

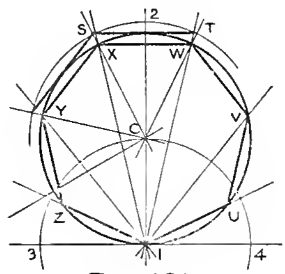


FIG. 101

(a) WHEN A SIDE, A-B, IS GIVEN. Fig. 100. With A or B as center, rad. A-B, describe a semicircle upon A-B extended. Divide this arc by trial (Art. 15(a)) into as many equal parts as the required polygon has sides (say 7). Through the center, B, and the second pt. of division, 2, draw B-2, which will be a second side of the polygon. Describe a ⊙ through A, B, and 2. (See Art. 40, Notes 1 and 2.) Apply A-B as a chord from 2, U, V, etc., and draw 2-U, U-V, etc., to complete the polygon.

Note 1.—Vertices U, V, W, and X may also be determined by radials from B, through 3, 4, 5, and 6, as shown.

Note 2.—Line B-1 would be the second side of a polygon of twice as many sides.

(b) WHEN THE CIRCUMSCRIBING CIRCLE IS GIVEN. Fig. 101. Draw a diam. 1-2, and a tangent 3-4 ⊥ to it. With 1 as center and any rad., preferably 1-C, describe a semicircle upon 3-4. Divide this arc and draw radials as in (a). Join pts. U, V, W, etc., thus found, to complete the polygon.

P. M. Divide the circumference by trial (Art. 15 (a)), and join the pts. I, U, V, W, etc.

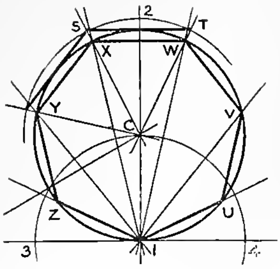


FIG 101

(c) WHEN THE INSCRIBED CIRCLE IS GIVEN. Fig. 101. Divide the circumference as in (b). Through these pts. of division draw radials C-W, C-X, etc., and obtain one side of the inscribed polygon, as X-W. Draw a tangent S-T || to X-W, which will be one side of the required polygon. The method of obtaining the others is evident.

P. M. Divide the circumference as in P. M. of (b); then proceed as above.

56. To construct a polygon similar to a given polygon, ABCDE, upon a given side, A′-B′. Fig. 102.

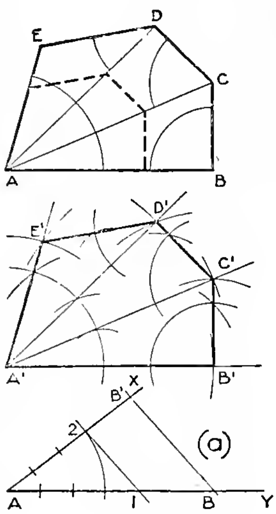


FIG. 102

(a) WHEN A′-B′ IS EQUAL TO THE CORRESPONDING SIDE, A-B. Draw A′-B′ equal to A-B. Locate vertices C′, D′, and E′ by drawing intersecting arcs with centers A′ and B′ and radii equal to the distances of C, D, and E from A and from B respectively.

SECOND METHOD. Divide the given polygon into △s by diagonals A-C and A-D. Construct ∠s at A′ and B′ equal to those at A and B, and at C′ and D′, equal to those at C and D (Art. 29); then the corresponding △s of the given and required figures will be similar and in this case equal.

P. M. Determine the vertices by Art. 57 and join them.

(b) WHEN A′-B′ IS GREATER OR LESS THAN A-B. Draw A′-B′ equal to the given length and proceed as in (a), second method. Then the corresponding sides of the given and required figures will be proportional.

Note 1.—It is sometimes convenient to lay off A′-B′ upon A-B or A-B extended, and then draw ||s to the other sides, as indicated by the dotted lines.

Note 2.—When the ratio of A′-B′ to A-B is given (as say 3 to 4) the length of A′-B′ may be determined by a scale of proportional lengths, Fig. (a). Draw indefinite lines A-X and A-Y at any ∠ with each other. On one, as A-Y, set off any length, A-1, and on the other A-2, in this case equal to $\frac{3}{4}$ of A-1. On A-Y set off the length of A-B. Draw 2-1, and B′-B || to it; then A-B′ will be equal to $\frac{3}{4}$ of A-B and thus be the required length of A′-B′. See Art. 30, Note.

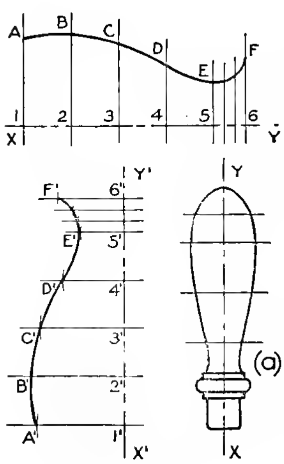


FIG. 103

57. To plot a figure similar to a given figure by means of a base line or center line, and offsets (in this case an irregular curve A-F). Fig. 103. In any convenient position with respect to the given figure draw base line X-Y. From A, F, and any number of intermediate pts., draw offsets ⊥ to X-Y. Having thus referred a sufficient number of limiting

pts., draw X′-Y′ as the line of reference for the required figure. Upon X′-Y′ set off 1′-2′, 1′-3′, etc., equal to 1-2, 1-3, etc., and draw offsets 1′-A′, 2′-B′, 3′-C′, etc., equal to 1-A, 2-B, 3-C, etc. Through pts. A′, B′, C′, etc., thus determined, draw the required curve. (See Art. 18(a).) Note application of principle in Fig. (a), also in Fig. 132(a), (b).

(a) To draw the figure to an enlarged or reduced scale (say enlarged in ratio 3 to 2). The co-ordinate distances would be $\frac{3}{2} = 1\frac{1}{2}$ times those of the corresponding pts. of the given figure, and may be obtained by Art. 56(b), Note 2; or proportional dividers may be used.

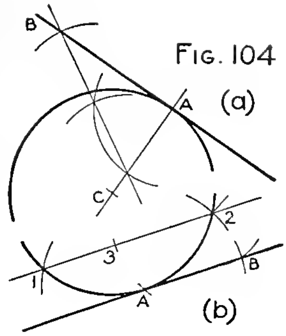


Fig. 104

58. To draw a tangent, A-B, to a circle, through a given point A.

(a) When A is on the circumference. Fig. 104(a). Draw rad. C-A, and tangent A-B ⊥ to it, Art. 34(c).

P. M. Draw A-B ⊥ to rad. C-A by Art. 8(d).

(b) When A is on the circumference and the center inaccessible. Fig. 104(b). With A as center, any rad., cut the curve at 1 and 2. Draw chord 1-2. Draw A-B || to 1-2 by Art. 36(b).

P. M. Obtain chord 1-2 as above. Draw A-B || to it by Art. 8(c).

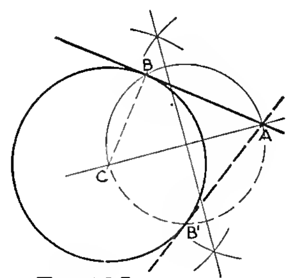


Fig. 105

(c) When A is outside of the circumference. Fig. 105. Join A to center C. Upon A-C draw a semicircle to determine pt. of tangency B. Draw tangent A-B. See Art. 34(c), Note 2.

Note.—A second tangent, A-B′, may be drawn, as indicated.

P. M. Draw A-B tangent to the ⊙ by eye. Locate pt. of tangency by a rad. C-B ⊥ to A-B, Art. 8(d).

59. To draw a tangent, A-B, to two given circles. Fig. 106. Draw line of centers 1-2. Subtract length of rad. of smaller ⊙ from that of the larger and draw concentric arc 3-4. Obtain tangent 2-3 by Art. 58(c). Draw rad. 1-A through 3, and make ∠ B 2 5 equal to ∠ A 1 4, Art. 29. Draw A-B, the required tangent.

Note.—To draw a tangent, C-D, passing between the centers—add length of rad. of smaller ⊙ to that of the larger, and draw concentric arc 6-7. Draw tangent 2-7, and rad. 1-7, locating pt. C. Make ∠ D 2 1 equal to ∠ 2 1 7, thus locating D. Draw C-D.

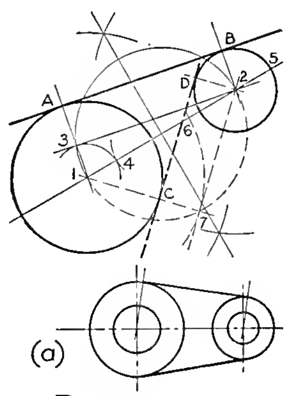


Fig. 106

P. M. Draw tangents A-B and C-D by eye. Locate pts. of tangency as in P. M. of Art. 58(c).

60. To draw a circular curve of given radius, D-E, tangent to a given circular curve and to a given straight line, A-B. Fig. 107. At distance D-E from A-B draw a || 1-2. Upon any rad., C-3 extended, set off 3-4 equal to D-E. Concentric with given curve, and with rad. C-4, draw an arc cutting 1-2 at 5, the center of the required curve. Line C-5 and a ⊥ to A-B from 5 determine pts. of tangency 7 and 6. See application in Fig. (b) at G.

Note.—The method of drawing a circular curve of given rad. tangent to two given circular curves is evident from Fig. (a).

61. To draw a circular curve tangent to two given straight lines, A-B and C-D. Fig. 108.

(a) WHEN A POINT OF TANGENCY, E, ON A-B IS GIVEN. Fig. (a). Extend A-B and C-D to intersect at 1, and make 1-E′ equal to 1-E. At E and E′ draw ⊥s to intersect at 3, the center of the required curve; or bisect the included ∠ B1D and draw ⊥ at E to cut the bisector 1-2 at 3.

Note 1.—When the vertex, 1, is inaccessible, the bisector may be obtained by Art. 28 Note.
Note 2.—The construction, when A-B and C-D are ||, or at right ∠s, is evident from Figs. (b) and (c).

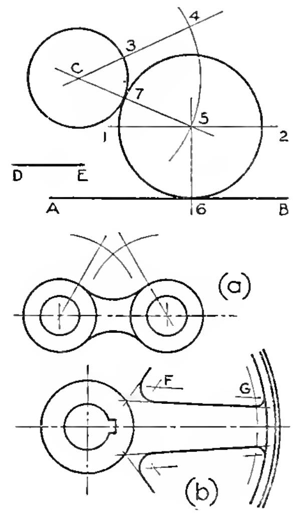


FIG. 107

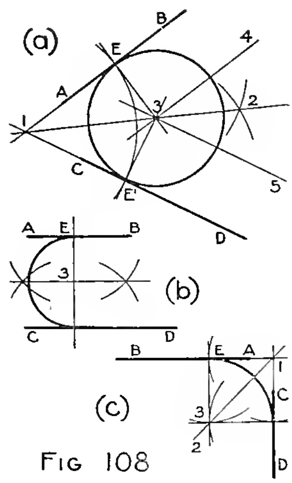


FIG 108

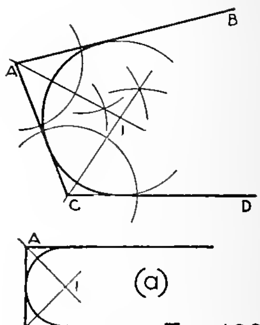


FIG 109

(b) WHEN THE RADIUS, 3-E, IS GIVEN. Fig. (a). At distance 3-E draw ||s to A-B and C-D, intersecting at center 3; or obtain bisector 1-2 as in (a) and a || to one side intersecting 1-2 at 3. See application in Fig. 107(b) at F.

Note.—When A-B and C-D are at right ∠s, the rad. may be applied as in Fig. (c).

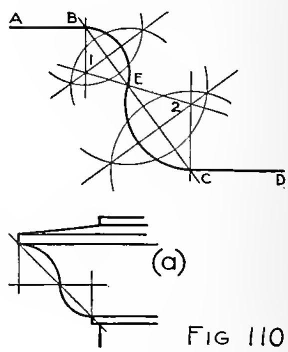


FIG 110

62. To draw a circular curve tangent to three straight lines, A-B, A-C, and C-D. Fig. 109. The construction is identical with that of Art. 42.

63. To draw circular curves tangent to two given parallel straight lines, A-B and C-D, at B and C, and to each other at any point E, in line B-C. Fig. 110. Draw ⊥ bisectors of B-E and E-C. At B and C draw ⊥s to A-B and C-D to cut the bisectors at 1 and 2, the centers of the required arcs.

64. To draw an ellipse when the axes, A-B and C-D, are given.

(a) BY FOCAL RADII. Fig. 111. Draw the axes ⊥ to each other at their middle pts. With either end, C, of the minor axis as center and rad. equal to $\frac{1}{2}$ of the major axis, cut the latter at F and F′, the foci of the ellipse. Between the center, E, and either focus place any pt., 1. With the foci as centers and rad. A-1, draw arcs upon opposite sides of A-B. With same centers and rad. B-1, cut these arcs at 2, 3, 4, and 5, which will be pts. of the required curve. Assume a sufficient number of other pts. for focal radii on A-B and proceed in like manner. Draw the curve through the pts. thus found, freehand. See Art. 18(a).

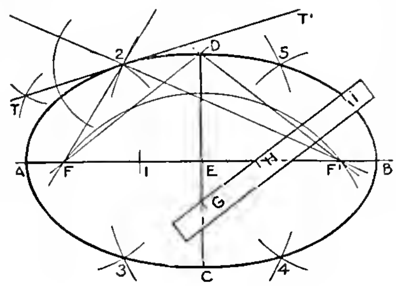


FIG. 111

Note.—The method of obtaining a tangent, T-T′, at a given pt., 2, in the curve is evident. See Art. 2(d).

(b) BY TRAMMEL METHOD. Fig. 111. On the st. edge of a piece of paper mark off G-I equal to $\frac{1}{2}$ of the major axis, and I-H equal to $\frac{1}{2}$ of the minor. Moving this trammel so that pt. G remains on the minor axis and H on the major, set off a sufficient number of pts. for the successive positions of I to determine the required curve.

Note.—Having located pts. for $\frac{1}{4}$ of the curve, corresponding pts. could be determined by Art. 57.

(c) BY REVOLUTION OF A CIRCLE. Fig. 112. Upon the axes describe ⊙s. Divide these ⊙s into the same proportional parts by diams. If the large ⊙ be imagined to revolve about axis A-B, pts. 1, 2, etc., will appear to move ⊥ to A-B. When 1 and 6 coincide with D and C, pts. 2, 3, etc., will have moved proportional distances which are determined by ||s to A-B from the corresponding pts. 2′, 3′, etc., of the smaller ⊙, at 2″, 3″, etc., of the required curve.

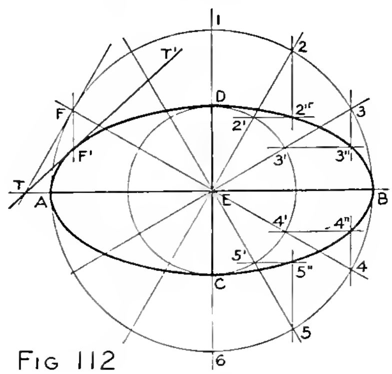


FIG 112

Note.—The figure indicates a second method of obtaining a tangent at a given pt. in the curve.

(d) BY PARALLELOGRAM METHOD. Fig. 113. Draw ||s to A-B and C-D through A, B, C, and D, forming a parallelogram. Divide A-F into any number of equal parts and A-E into the same number of equal parts. Through the pts. of division on A-F, draw D-1, D-2, D-3. Through the corresponding pts. on A-E draw C-1, C-2, C-3 intersecting the lines from D at 1′, 2′, 3′,

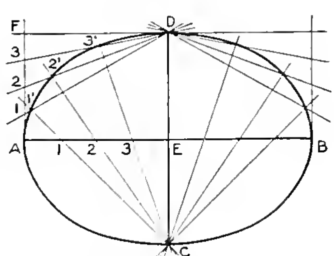


FIG. 113

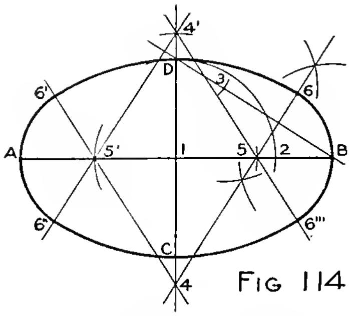


FIG 114

which will be pts. in the required ellipse. In like manner find pts. for remainder of curve.

Note 1.—The same construction applies when any two conjugate diameters are given.

Note 2.—The method of inscribing an ellipse in any given parallelogram (not square) is evident.

(e) BY CIRCULAR ARCS. Fig. 114. The following is one of several methods of approximating an ellipse: Draw D-B. Make 1-2 equal to 1-D and D-3 equal to 2-B. Draw a ⊥ bisector to 3-B, cutting C-D extended at 4, and A-B at 5. Make 1-5′ equal 1-5 and 1-4′ equal 1-4, and draw 4-6′, 4′-6″, and 4-6‴. With 5 and 5′ as centers, rad. 5-B, draw arcs 6-6‴ and 6″-6′; then with 4 and 4′ as centers, rad. 4-D, draw arcs 6′-6 and 6‴-6″ to complete the curve.

CHAPTER V

ORTHOGRAPHIC PROJECTION

65. General Principles. It has been noted that mechanical drawings are made for the purpose of showing the exact facts of form, dimension, and arrangement of parts in objects of a structural character. (See Art. 1.) To express these facts fully and clearly it is necessary to represent the object by two or more related drawings each of which gives certain information that the others lack.

These drawings, though made upon one plane, the paper, by the methods of Chap. IV, are regarded as projections of the image of the object upon different planes || to the axes or principal dimensions of the object, and imagined to be obtained by means of ⊥s to those planes from all pts. of the object; that is, in accordance with the principles of *Orthographic* (true drawing) *Projection.*

(a) In Fig. 115(a), ABCD is a pictorial drawing of a hollow rectangular block, placed squarely in front, with the center of the opening on the level of the eye. By experiment with a similar object, it will be observed that the front surface, being at right ∠s to the direction in which it is seen, appears in its exact form.

The surfaces of the opening, although at right ∠s with the front, appear foreshortened and to incline towards each other; the farther lines appear shorter than the nearer, and the receding lines to incline and converge towards a pt. at the center.

The apparent decrease in size, foreshortening, inclination, and convergence is due to the position of the lines and surfaces of the object with respect to the eye of the observer, and, obviously, if the position of the eye be changed, the appearance will also change. Thus, if the eye be moved a certain distance upward, the object would appear as shown in Fig. (b) and if moved upward to the right, as in (c).

It is evident that none of these pictorial representations shows the exact form, size, and relation of all the lines and surfaces.

(b) Let LMNO (Fig. 115(a)) represent a vert. pane of glass or wire screen placed || to the front surface of the object. Consider this glass or screen to be merely

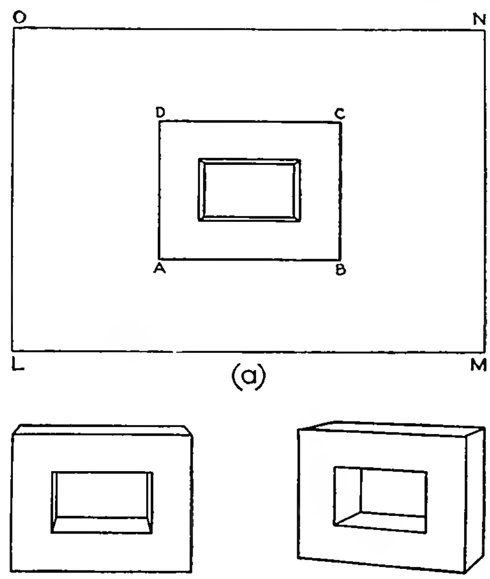


FIG. 115

a plane, and the picture ABCD, as obtained by tracing lines upon the plane to exactly cover the outlines of the object seen through it. Since the plane is nearer to the eye than the object, and the rays of light converge from the object to the eye, it follows that all lines of the tracing must be shorter than those of the object; also, that if the object be projected forward until its front surface coincides with the plane, the tracing of that surface would be identical both in form and dimensions with the surface itself.

(c) If now, instead of moving the object, lines be imagined to extend from all its pts., A, B, C, D, etc., ⊥ to the plane, as shown pictorially in Fig. 116, these ⊥s would intersect the plane at A^V, B^V, C^V, D^V, etc. These pts. are called *projections* of the pts. of the object, and lines A^V-B^V, B^V-C^V, etc., joining them, will be projections of the lines and surfaces of the object.

The plane is a *plane of projection* and the ⊥s are the *projectors* of the pts.

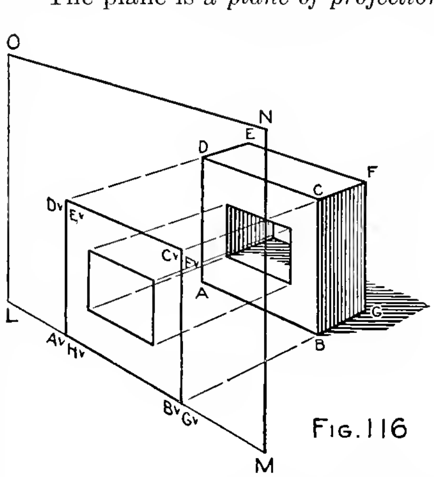


Fig. 116

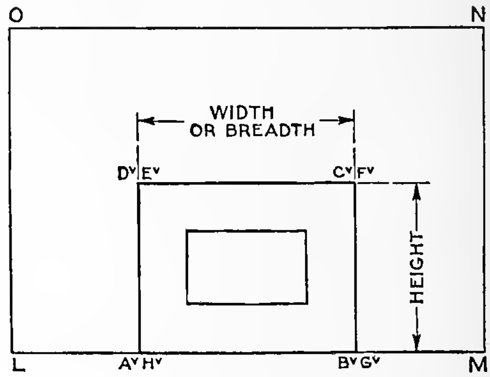


Fig. 117

(d) Since the projectors are || to each other, and the rear pts. of the object are perpendicularly back of the front pts., it follows that the projections of the front and rear pts. will coincide, as indicated in the figure. The projection, when viewed squarely, as in Fig. 117, thus shows what the eye would see if imagined to be directly opposite each pt. of the object at the same time; namely, the exact form and dimensions of the front and rear surfaces, and the dimensions of the object from left to right and bottom to top.

(e) Although in this case the first dimension is the length and the latter the width, it is convenient in speaking of the dimensions of an object in a definite position to call the hor. dimension from left to right the *width*, or *breadth*, that from front to back the *depth*, and the vert. dimension the *height*, regardless of their extent.

In the notation of this proj. and others which will be explained, the first letter in each instance indicates the pt. of the object nearer the plane, and the small letter the plane upon which the proj. of that pt. lies. To avoid confusion, the notation of the opening is omitted.

(f) Since the three dimensions of an object are ⊥ to each other and a plane has but two dimensions, it follows that when two dimensions of the object are

projected in their exact size the remaining dimension is not seen; that is, no more than two dimensions can be shown in their exact size and relation in one proj.

Hence, to show the dimension from front to back (depth), another proj. upon a plane ⊥ to the *front* or *vertical plane* must in like manner be obtained.

Thus in the pictorial illustration Fig. 118, $D^HC^HF^HE^H$, etc., is the proj. of the object upon a *top* or *horizontal plane* ONQP, and $B^PG^PF^PC^P$, etc., its proj. upon a *side vertical* or *profile plane* MRQN, at right ∠s to the first two.

Note.—The relation of the planes may be illustrated by means of a paper box, hinged panes of glass, or screens.

(g) To show these projs. as they are generally arranged in a mechanical drawing, the planes of two of the projs. are imagined to be revolved about their lines of intersection into the plane of the other regarded as the plane of the drawing, as in Fig. 119.

(h) It should be noted that the projs. upon the top and side planes are precisely the same as would be obtained upon the front plane if the

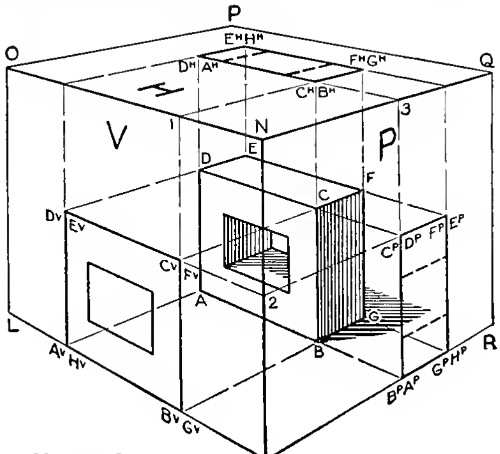


FIG. 118

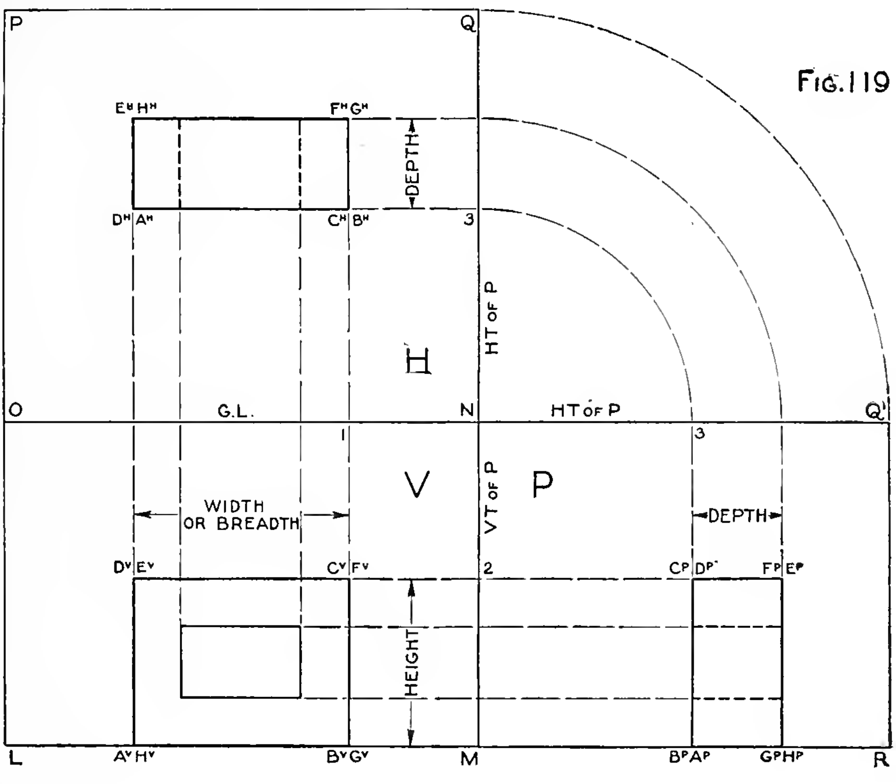


FIG. 119

object were turned from the position given so that its dimensions of width and depth, and then its height and depth, are || to that plane.

The opening cannot be seen when the object is looked at squarely, either from above or from the side, but as it is necessary to show its projs. upon the top and side planes,—the lines whose projs. do not coincide with those of *visible lines* are represented by dashed lines, to indicate that they are *invisible* or hidden. Observe that the outer lines of all projs. represent visible lines of the object; those within represent hidden lines when seen in the other projs. to lie below or behind some solid portion.

(i) It is evident that the three dimensions are shown by any two of the projs.; that two ⊥ projs. are, therefore, necessary to show the three dimensions; and that the three projs. together determine completely and clearly the exact form, size, and relation of all lines and surfaces of the object.

(j) These three mutually ⊥ planes of proj. are called the *co-ordinate planes,* and for brevity are denoted by V, H, and P respectively.

A proj. is named from the plane upon which it is imagined to be obtained, not from the particular part seen or shown. Thus those upon V, H, and P are respectively the *vertical, horizontal,* and *profile projection.*

In practical drafting, the first is called a *front elevation* or *front view,* the second a *plan* or *top view* and the third a *side elevation* or *side view.*

The terms "plan" and "elevation" are used chiefly in architectural drafting; the term "view" is more generally used.

(k) The line of intersection of V and H is called the *ground line* or *trace* of V and H, and is denoted by G L.

When looking squarely at V, the G L represents H; and when looking at H, it represents V. The line of intersection of V and P is called the *vertical trace of P;* that of H and P is the *horizontal trace of P.* These are denoted by V T of P and H T of P.

When looking at V or H, these traces indicate the position of P. When looking at P, they represent V and H. The verts. and hors. from the views to the traces represent the projectors to the planes.

(l) When H and P are revolved, the front and top views of any pt. are seen to lie in the same vert.; the front and side views in the same hor.; and its top and side views equally distant from the G L, and V T of P, respectively.

Rules 1, 4, 5, and 7 (Art. 74) may here be noted.

(m) Views could in like manner be obtained upon planes auxiliary to the co-ordinate or principal planes, V, H, and P; namely, upon a profile plane at the left of the object, upon a bottom plane || to H, upon a rear plane || to V, and upon planes oblique to either two of the co-ordinate planes.

We may thus have front, top, right and left side, bottom, rear, and oblique views.

With the exception of the latter, the relative arrangement of these views in a mechanical drawing would generally be as indicated in Fig. 120. See Art. (i).

Note that the line of each view (excepting the rear) nearest the front view represents the front line or surface of the object in that view.

66. To draw the front, top, and side views of a rectangular object. Suppose it is required to draw these views of the block (Fig. 119(a)), its position and dimensions being given.

(a) First draw ONQ′ and MNQ to represent the traces of V, H, and P. That portion of the paper below O-N and to the left of M-N will represent the front plane, that above O-N and to left of N-Q the top plane, and that to the right of M-N and below N-Q′ the right side plane. The outer limiting lines of the planes are always omitted.

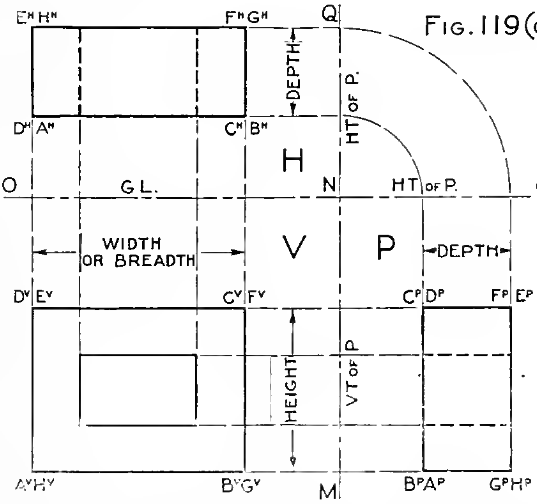


FIG. 119(a)

(b) Since the distance of the object from the planes is immaterial, the views may be drawn any distance from the G L and traces of P. Hence, at any convenient distance below O-N and to the left of M-N, draw rectangle $A^VB^VC^VD^V$ for the main lines of the front view, making the hor. and vert. dimensions equal to the breadth and height respectively, of the object. The opening should at first be disregarded.

(c) The top view of each pt. must be in a vert. through its corresponding front view, Art. 65(1). As in this case all pts. of the front face are equally distant from V, draw the projectors from the front view, and at any convenient distance above the G L, draw the hor. D^H-C^H for its top view.

As the rear face is || to the front, its top view will be E^H-F^H, at a distance from D^H-C^H equal to the depth of the object. As the side faces are ⊥ to H, their top views will be the verts. D^H-E^H and C^H-F^H, thus completing the rectangle $D^HC^HF^HE^H$ for the main lines of the top view of the object.

(d) From Art. 65(1) it follows that the side view of each pt. will be in the hor. through its corresponding front view and at the same distance from the V T as its top view is above the G L. Hence, draw indefinite hors. from the front view, and from the top view to N-Q′.

Then as N-Q and N-Q′ both represent the H T of P, describe arcs with N as center, to carry the pts. from N-Q to N-Q′. From these pts. draw verts. to intersect the projectors from the front view, thus determining B^P, G^P, F^P, and C^P and forming the main lines of the side view.

(e) Similarly, if the side view is first obtained, the reverse of the above process will determine the top view.

(f) Now, returning to the front view, draw the rectangle to represent the opening, then project as before, to complete the other views.

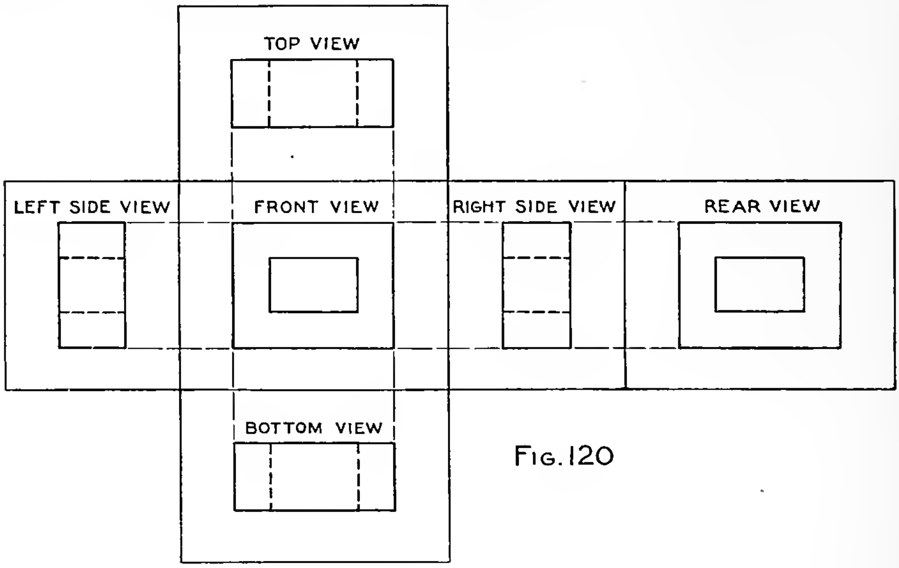


Fig. 120

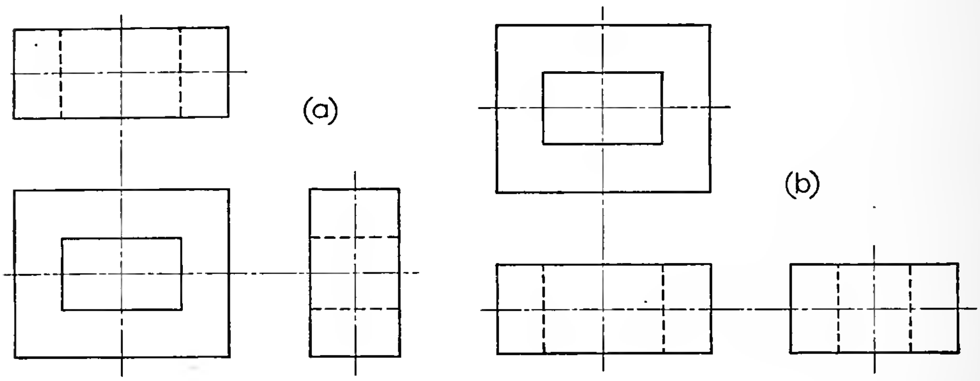


Fig. 121

(g) Practical Methods. In practical drafting, only such portions of the projectors are penciled as may be necessary to locate the required pts. The traces of the planes of proj. are also omitted; center, base, or other lines || to the positions of the traces being utilized as reference lines in locating the views, practically as though such lines were the actual traces of the planes. Thus, in determining the views (Fig. 119(a)) the lower hor. of the top view and left vert. of the side view could have been located any convenient distance from the front view, and the depth set off from top to side or vice versa, by means of the dividers.

Fig. 121(a) shows the views with the traces and projectors omitted. In this case all measurements were set off with reference to lines representing the axes of the object, called *center lines*.

It is evident that a C. L. of a view may be regarded as the trace of a central plane ⊥ to the plane of that view.

Fig. 121(b) shows the same object in a different position. Working drawings of an object composed of several rectangular parts are shown in Figs. 179, 180.

67. Objects Having Surfaces Oblique to the Co-ordinate Planes. The form of an object is frequently such that some of its surfaces and lines will be oblique to the planes of one or more of the views; and, therefore, foreshortened in those views. Thus in the pyramid (Fig. 122) the front and rear faces are oblique to V and H, the left and right faces to H and P, and its slant edges to V, H, and P. These surfaces and lines are, therefore, foreshortened in all of the views.

The base is || to H and has two of its edges || to V and two || to P. When thus placed the object is || to V, H, and P as much as it can be, since its axes or principal dimensions are also || to those planes, and the views enable the form of the object as a whole to be determined, as in the case of a rectangular object.

Rules 2, 3 and 6 (Art. 74) may here be noted.

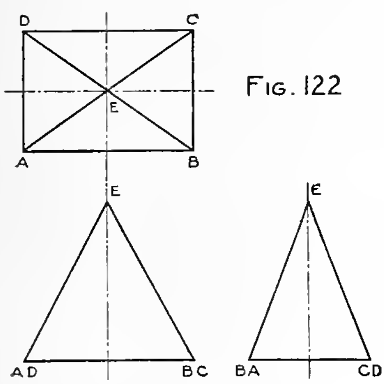


Fig. 122

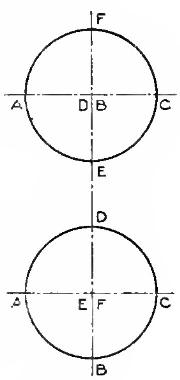


Fig. 123

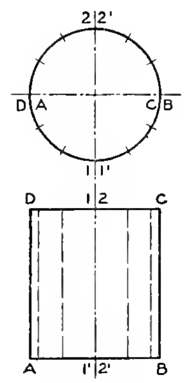


Fig. 124

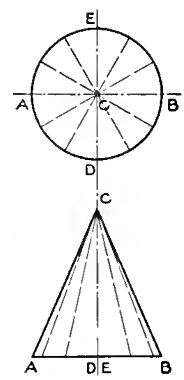


Fig. 125

68. Objects Having Curved Surfaces.

(a) Any view of a sphere is a ⊙ equal to a great ⊙ of the sphere, Fig. 123. Observe that the great ⊙ ABCD is || to V, AECF || to H, and DEBF || to P.

The view of a right circular cylinder upon a plane to which its axis is ⊥ is a ⊙. Its view upon a plane || to the axis is a rectangle. Thus in Fig. 124 the bases are || to H and ⊥ to V; they are, therefore, seen upon H in their exact shape, and upon V as || hors. equal to the diam. of the base. The elements are || to V and ⊥ to H and, therefore, seen upon V in their exact length, and upon H as pts. in the ⊙.

The views of a right circular cone whose axis is thus related to the planes are a ⊙ and a △. Fig. 125. The outer elements only being || to V, they only are seen upon it in their exact length. Intermediate elements are unequally inclined to V and, therefore, unequal upon it. As all the elements are equally inclined to H, they are equally foreshortened upon H. Note that as the third view in each case would be the same as one of the others, its representation is unnecessary.

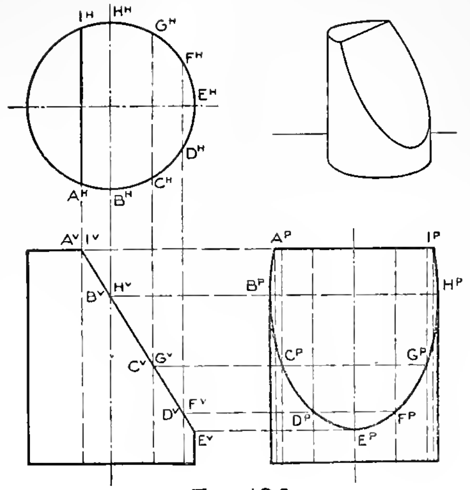


FIG. 126

(b) Equidistant elements of a right circular cylinder or cone may be determined by equal division of the base or other ⊙ of the surface, in the view in which that ⊙ is seen in its exact shape. Twelve are usually sufficient.

(c) Fig. 126 represents a truncated cylinder. As the elements are ⊥ to H, the top view of the curve of the oblique surface coincides with that of the base. As the surface is oblique to P, its side view will also be a curve. To draw this view it is necessary, since there are no vertices as in rectilinear figures, to obtain a sufficient number of its determining pts., by assuming these first in the known (front and top) views of the curve. Having located these pts. in the side view the curve is drawn through them, as shown. See Art. 18(a).

In cylindric or conic surfaces these pts. may be regarded as the ends of elements.

69. Projections upon Oblique Auxiliary Planes. When it is necessary to represent an object so that some particular surface, ⊥ to one plane but oblique to another, shall be shown in its true or exact shape, an *auxiliary view* upon a plane || to that surface may be obtained.

(a) In Fig. 127, $D^AB^AC^A$, etc., represents a proj. upon an aux. plane A, || to the surface DBC, that is, upon a plane ⊥ to V, but oblique to H. The method of obtaining this view differs from that of obtaining a side view only in that the V T in this case is || to $D^VB^VC^V$, instead of ⊥ to the G L. Having located the traces of A, draw ⊥s to the V T from the front view and intersect these by projecting from the top view as shown, or transfer the pts. with dividers as in Art. 66(g). Joining the pts. thus determined will form the required view. Note application of principle in Figs. 144, 182.

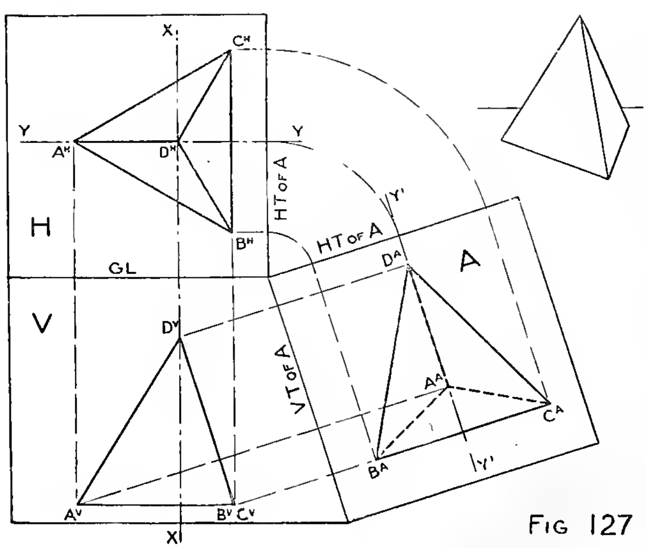
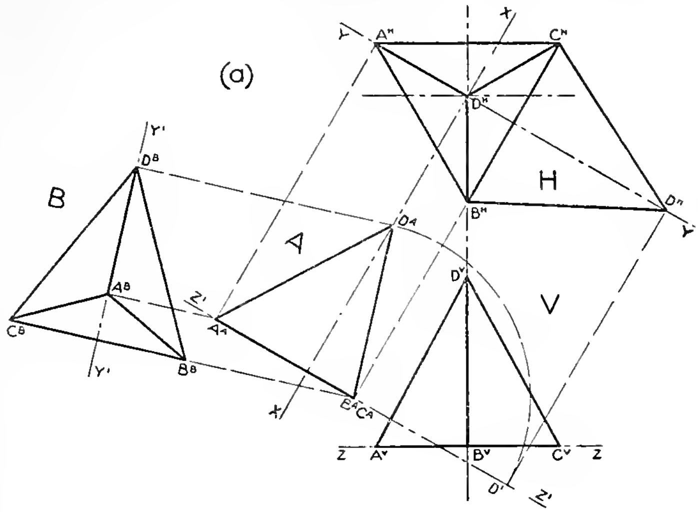


FIG 127

(b) In Fig. 128(a) an aux. view $A^AB^AD^A$, upon a plane, A, ⊥ to H and || to a central plane, Y-Y, is shown. In this case the view was determined by

means of C. Ls. and base lines regarded as the traces of planes ⊥ to those of the views. The method differs from that of obtaining the front view in Fig. 127 only in the changed positions of the central planes X-X and Y-Y. Thus Y-Y is the H T of the given central plane; X-X is the H T, and trace upon A, of a second central plane ⊥ to Y-Y. Z-Z is the V T of the plane of the base, and Z′-Z′ drawn any convenient distance from Y-Y and ∥ to it is the trace of the base plane upon A.



Perpendiculars to Z′-Z′ from A^H, B^H, and C^H determine A^A, B^A, and C^A; setting off the height of D above Z-Z from the front view and joining D^A, A^A, and B^A completes the required view.

(c) Fig. 128(a) also shows the method of obtaining an aux. view $D^BC^BB^B$, upon a plane, B, ∥ to a surface DBC, which is not ⊥ to the plane of either of the given views, that is, not shown as a line, but ⊥ to which a plane, Y-Y, can be directly determined.

The aux. view $A^AB^AD^A$, is first obtained as in the preceding case. Y′-Y′ ∥ to $D^AB^AC^A$ is the trace upon B of the ⊥ plane Y-Y.

Perpendiculars to Y′-Y′ from A^A and D^A determine A^B and D^B; setting off the distances of B and C from Y-Y, ⊥ to Y′-Y′, and joining pts. A^B, B^B, C^B, D^B completes the required view.

(d) Fig. (b) shows the method of obtaining an aux. view upon a plane, B, ⊥ to the axis of an object which is oblique to V, H, and P. Note that the views upon A and B determine the true dimensions of the prism.

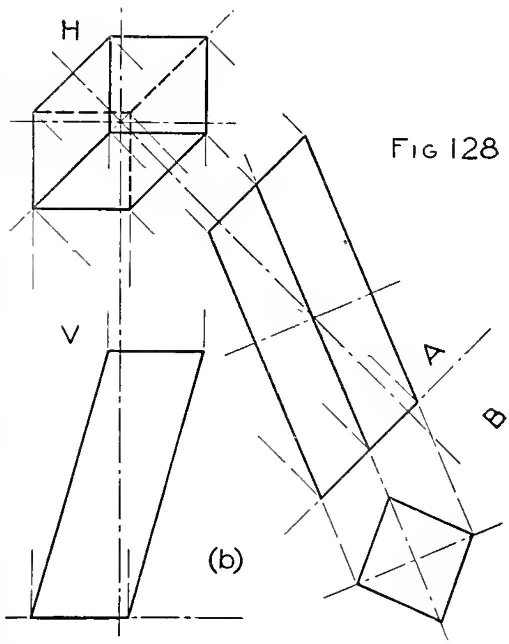


FIG 128

(e) In a curvilinear object, it is necessary to assume pts. in the known views of the curves and then obtain these in the aux. view, as is evident from Art. 68(c).

(f) When the true shape of a particular surface only is required the same method, or that of Art. 70, may be used.

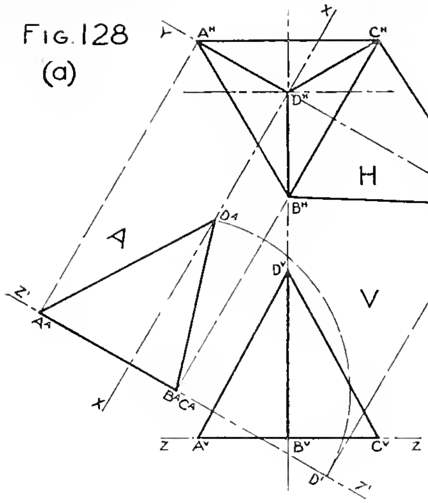


FIG. 128 (a)

70. Revolution of Surfaces. It is frequently desirable to determine the true shape of a surface by revolving it about an axis until || to V, H, or P.

(a) Fig. 129(a) represents a truncated hexagonal prism with its oblique surface ABCDEF revolved about an imaginary axis ⊥ to V through pt. A, until it is || to H, upon which it is, therefore, seen in its true shape A′B′C′D′E′F′.

In revolving a surface, each pt. not in the axis of revolution describes an arc whose plane is ⊥ to that axis. In this case, therefore, the arcs are seen as arcs in the front view and as lines || to the G L, or C. L., A^H-D′, in the top view. Hence, the front view of the surface remains a line of the same length, and the distances of the pts. of the surface from V also remain unchanged.

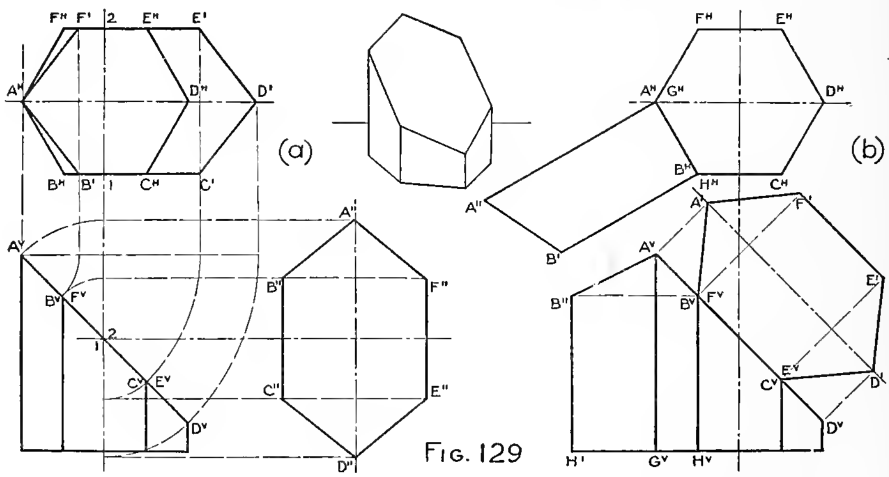


FIG. 129

The surface could in like manner be revolved || to H, or to P, about any other axis ⊥ to V. Thus A″B″C″D″E″F″ represents it revolved about 1-2 until || to P.

Fig. (b) represents the surface revolved about its side B-C until || to V. As B-C is || to V, the front views of the arcs described by A, F, E, and D are ⊥s to B-C at A^V, B^V, C^V, and D^V; and as the true distances of A, F, E, and D back of B-C are seen in the top view, these distances are set off on the ⊥s at A′, F′, E′, and D′ as shown.

The figure also shows a lateral surface revolved about its base edge, G-H, until || to H; and, about the lateral edge, A-G, until || to V. Note application of principle in Fig. 140 to the revolution of an imaginary surface on C-D. See also Figs. 145, 153, 158, 159, 161(b).

(b) In Fig. 128(a), a surface DBC, oblique to V, H, and P, is shown revolved || to H about its base edge B-C. As B-C is || to H, the top view of the arc described by pt. D will be a ⊥ to B^H-C^H, coinciding with Y-Y. Hence, the true distance of D from B-C is determined, in this case, by an aux. view upon a plane A, || to the central plane Y-Y, to which the surface DBC is ⊥. Art. 69.

Rule 8 (Art. 74) may here be noted.

71. True Length and Position of Lines Oblique to the Co-ordinate Planes. To determine the true length of a line oblique to the planes, the line may be projected upon a || aux. plane, or revolved || to a plane of proj., practically as in the case of a surface.

(a) First Method. To obtain the true length of A-D (Fig. 128(a)) upon an aux. plane ⊥ to H. The method is evident from Art. 69(b). A^A-D^A is the true length, and the ∠ it makes with the H T of plane Y-Y containing the line is the true ∠ the line itself makes with H.

To obtain the true length of A-D (Fig. 130) upon an aux. plane A ⊥ to V, regard A^V-D^V as the V T of the plane containing the line; Y-Y as the H T of a central plane ⊥ to the first; and Y′-Y′ placed any distance from A^V-D^V and || to it, as the trace of this second plane upon the aux. plane A.

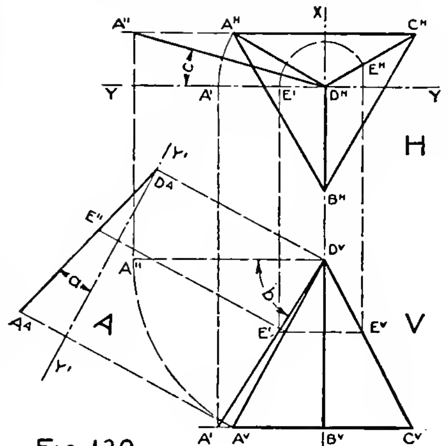


FIG 130

Projecting from A^V and D^V ⊥ to Y′-Y′ obtain D^A, and set off the ⊥ distance that A is back of Y-Y. Then A^A-D^A will be the required true length and (a) the true ∠ that the line itself makes with V.

(b) Second Method. If the line A-D be revolved || to V about an axis ⊥ to H through D, the line remaining at the same ∠ with H and pt. D fixed, pt. A will describe a hor. arc, the top view of which will be the arc A^H-A′, and the front, the hor. A^V-A′. In this position, therefore, the top view of the line remains unchanged in length, while the front A′-D^V shows the true length of A-D and the true ∠ (b) that it makes with H.

As all of the edges meeting in the vertex D are equal and equally inclined to H, A′-D^V is the true length and (b) the true ∠ of all.

Again, as all pts. in the revolved line remain on the same levels, they describe similar hor. arcs. The true distance from D of any pt., as E on D-C, may, therefore, be found by drawing a hor. from that pt. to the true length line A′-D^V, as proved by the top view which shows E revolved into A′-D^H. E′-D^V is, therefore, the true length of E-D.

The figure also shows the line A-D revolved || to H about an axis ⊥ to V, through D. A″-D^H is, therefore, the true length and (c) the true ∠ of A-D with V.

The line could in like manner be revolved about an axis through A.

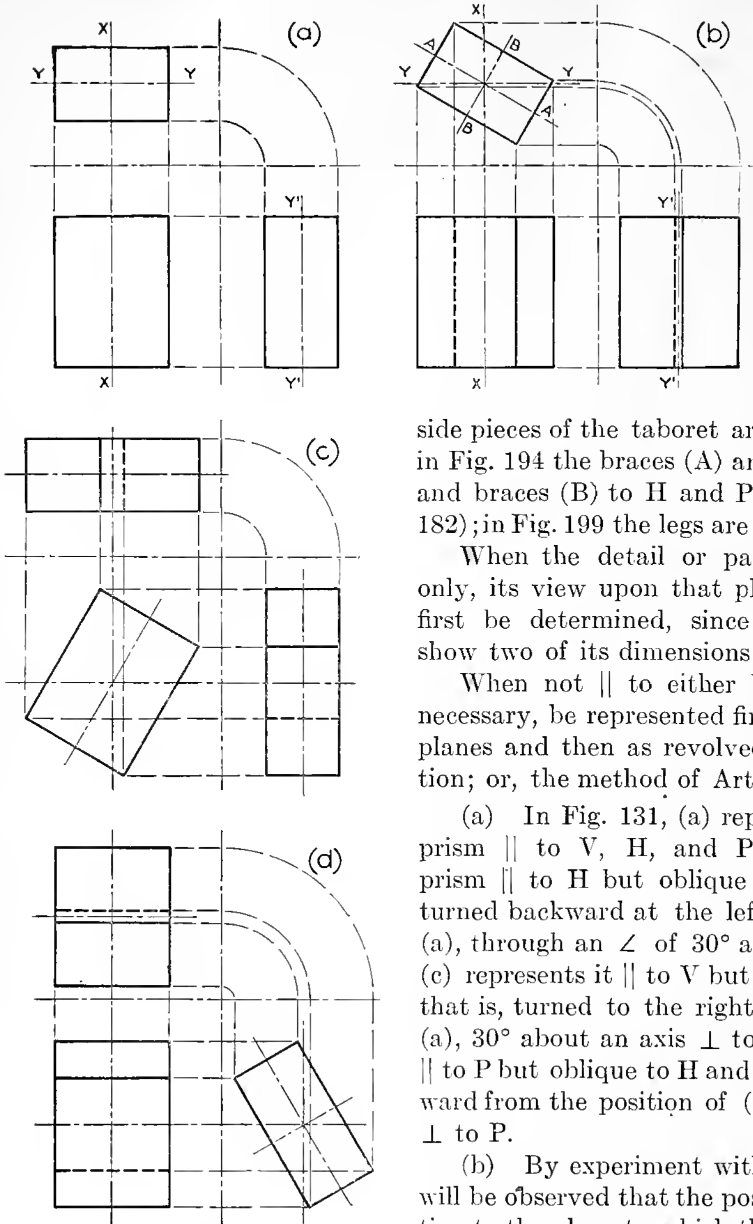


Fig. 131

72. Objects Oblique to the Co-ordinate Planes. It frequently occurs that the axes of one or more integral parts of an object are oblique to those of the main portion, and, therefore, to the planes of one or more of the views. Thus, in Fig. 193 the left and right side pieces of the taboret are oblique to V and P; in Fig. 194 the braces (A) are oblique to V and H, and braces (B) to H and P (see also bolts in Fig. 182); in Fig. 199 the legs are oblique to V, H, and P.

When the detail or part is || to V, H, or P only, its view upon that plane should, as a rule, first be determined, since that view only will show two of its dimensions in their exact size.

When not || to either V, H, or P, it may, if necessary, be represented first as || to one of those planes and then as revolved to the required position; or, the method of Art. 73 may be used.

(a) In Fig. 131, (a) represents a rectangular prism || to V, H, and P. (b) represents this prism || to H but oblique to V and P, that is, turned backward at the left from the position of (a), through an ∠ of 30° about an axis ⊥ to H. (c) represents it || to V but oblique to H and P, that is, turned to the right from the position of (a), 30° about an axis ⊥ to V. (d) represents it || to P but oblique to H and V, that is, turned forward from the position of (a), 30° about an axis ⊥ to P.

(b) By experiment with the actual object, it will be observed that the positions of its lines relative to the plane to which the axis of revolution is ⊥ remain unchanged. It follows that the object may be turned through any ∠ without changing the form and dimensions of the view upon that plane. Thus, in Fig. 131, the top view in (b), the front view in (c), and the side view in (d) are the same as the corresponding views in (a), save that they show the changed relation of the object to the planes to which the axis of revolution is ||. The views upon the latter planes change in outline with each position of the revolution, but as no pt. changes its distance from the

plane to which the axis is ⊥, the dimensions || to the axis also remain unchanged. Thus, corresponding pts. of the front and side views in (b) and (a) are at the same distances from the G L, and H T of P; those of the top and side views in (c) and (a) at the same distances from the G L, and V T of P; and those of the front and top views in (d) and (a) at the same distances from the traces of P. Note Rule 8, Art. 74.

(c) In determining the views of an object thus revolved, having located the G L and traces of P, or equivalent reference lines*, draw the main axis or axes of the unchanged view at the required ∠s with the planes to which the object is oblique. (See lines A-A and B-B in Fig. (b).) Measuring upon, and || to these axes, construct the view. From this view draw projectors to a second plane and set off upon them the unchanged dimensions* || to the axis of revolution, measuring from the trace of the first plane, or equivalent reference line. Joining the pts. thus determined will complete the second view. From these, the third may be obtained as in Art. 66.

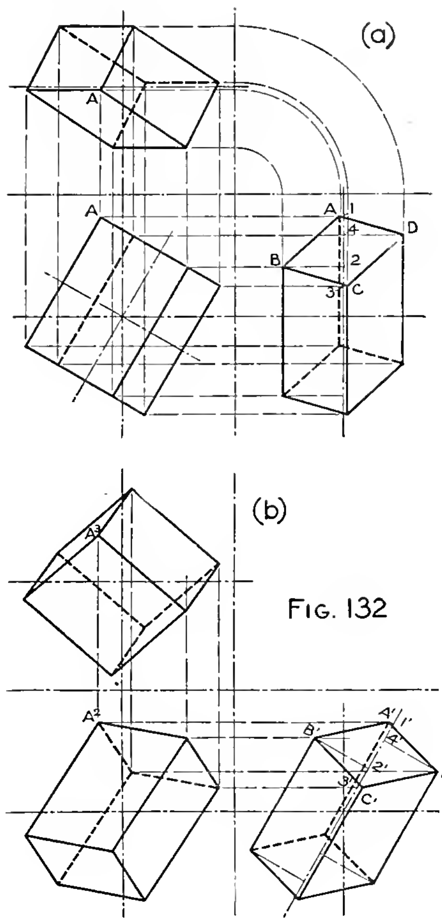


FIG. 132

(d) In Fig. 132, (a) and (b) represent the same prism when oblique to V, H, and P. (a) represents it as turned to the right from the position of (b) in Fig. 131, 30° about an axis ⊥ to V; (b) as turned backward from the position of (a), 30° about an axis ⊥ to P.

In determining these views the same principles apply as in the preceding cases. By assuming and representing an object in a primary position, as nearly as may be like that required, and then as revolved, any conceivable position may be represented.

Observe that the side view in Fig. (b) was plotted from Fig. (a) by Art. 57.

(e) In an object having curved surfaces, pts. must be assumed in the primary positions of the curves, as explained in Art. 68(c). Note applications of principle in Fig. 193.

*In practical work the traces and projectors are omitted, as explained in Art. 66(g). They are shown in Fig. 131 merely for illustration.

(f) Instead of representing each position separately, the required views may be obtained by revolution about a C. L. of a primary position as in Fig. 133(a), or about an axis || to that C. L. as in Fig. (b).

73. Partial Views, and Use of Auxiliary Views in Determining Required Views.

(a) Partial views, and aux. views (views of revolved lines or surfaces, and oblique views) may frequently be used in place of complete or regular views and thus economize space and labor. Thus in Fig. 214 half of the top view would suffice to determine the required pts. of the front; in Fig. 153 a revolved half-base is used for the same purpose; in Fig. 147 half only of the side view of A and C is necessary; in Fig. 144 half of the oblique view would suffice; in Fig. 145 the revolved half-bases of (B) and (C) dispensed with a side view; in Fig. 146 a view ⊥ to the axis of (B) or a revolved imaginary ⊙ is necessary to determine positions of elements.

(b) In representing objects oblique to the co-ordinate planes, primary positions may be omitted and the missing dimensions of the required views determined by the same general methods.

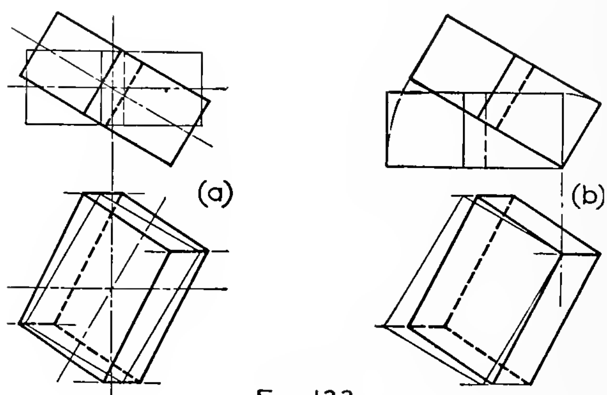


Fig. 133

To illustrate, Fig. 134(b) represents a pentagonal prism with its axis and lateral edges || to H and at 30° back to the right with V. Its bottom face also is || to H. Instead of representing the prism first as || to V and H as in Fig. (a), and then as revolved about an axis ⊥ to H until its lateral edges make the required ∠ of 30° with V, the representation of the first position may be omitted and the missing dimensions determined as follows:—

First locate X-X, Y-Y, Z-Z, and Y′-Y′ for the C.Ls. of the required views. Through the center of the top view draw V-V at 30° with Y-Y for the H T of a central plane containing the axis and W-W for the H T of a central plane ⊥ to V-V. Equally distant from the center and at a distance apart equal to the axis of the prism, draw indefinite ⊥s to V-V for the bases. Now obtain an aux. view upon a plane || to the central plane W-W. The H T of this plane would be ||

to W-W, and the trace of the hor. central plane Z-Z, upon the aux. plane, would also be || to W-W. Hence, at any convenient distance from either base, draw this trace Z′-Z′ and about its intersection with V-V construct the view, noting that as the lower surface of the prism is || to H, the line A-B will be || to Z′-Z′, as shown. Projecting perpendicularly to W-W from this view, complete the top

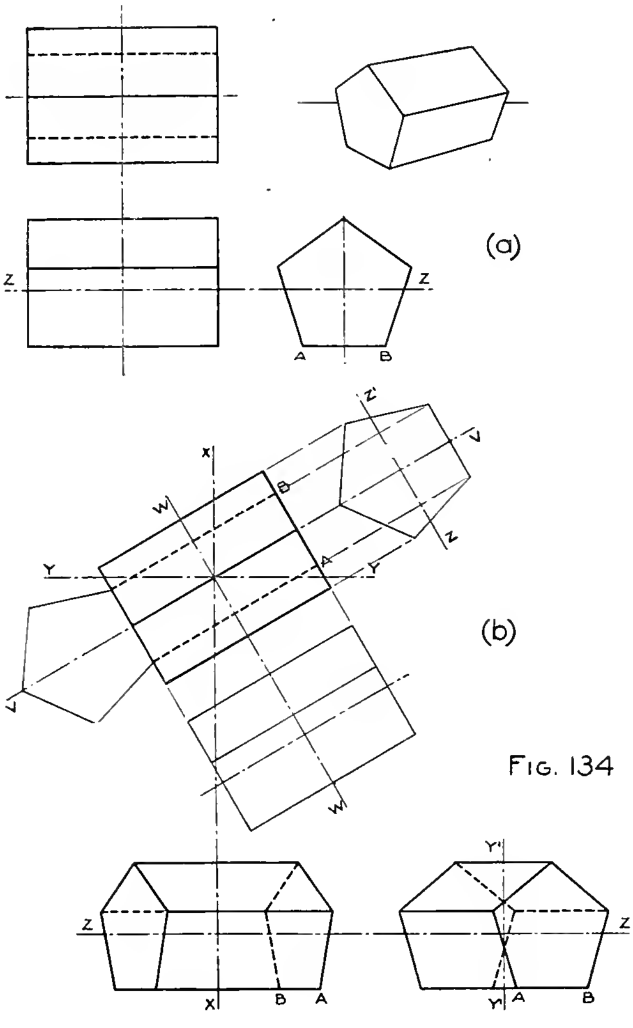


Fig. 134

view. Project next to V and complete the front view, obtaining the distances of pts. above and below Z-Z by measuring from Z′-Z′ in the aux. view. The missing dimension in this case could also be obtained by revolving a base || to H, then by counter revolution projecting back to the top view, as shown.

In some cases a view upon an aux. plane || to the central plane V-V, as shown, would be necessary instead of, or in addition to, that of the end.

Fig. 135 represents the same prism with its axis || to V and at 60° up to the right with H. Its rear face also is || to V.

Fig. 136 represents it with its axis || to P and 30° forward with V. Its left face also is || to P.

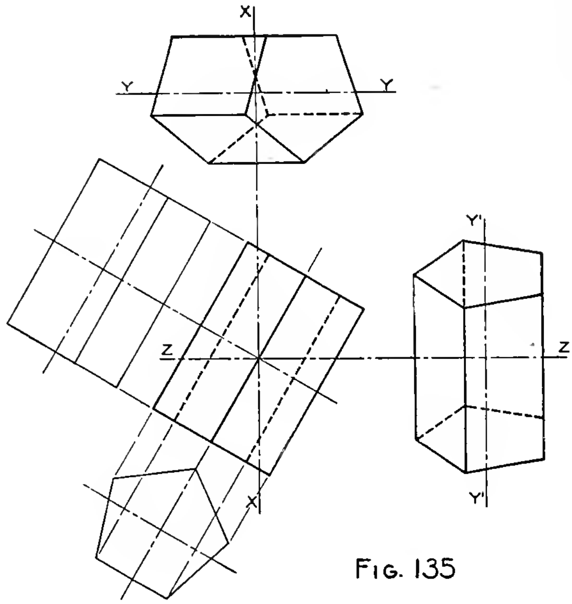


FIG. 135

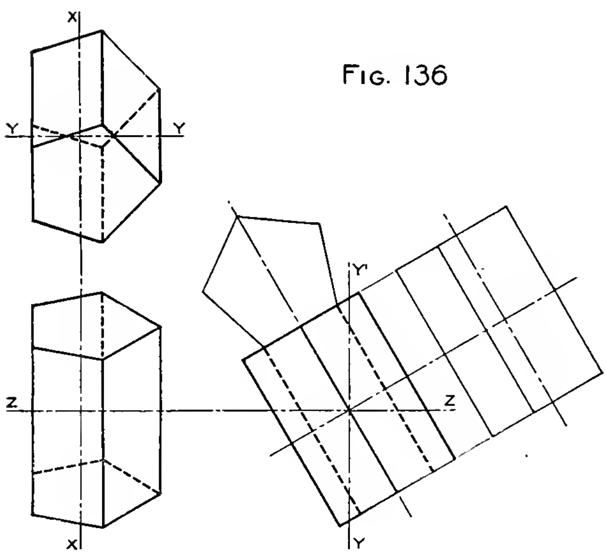


FIG. 136

The methods of obtaining the missing dimensions are identical with those of the preceding case and are shown by the figures.

(c) Fig. 137 represents the prism with its axis inclined up to right at 60° with H and in a plane at 45° back to left with V. One of rear faces also is at 45°

with V. This is identical with a revolution from the position of Fig. 135, 45° about a vert. axis, but instead of representing the prism first at 60° with H, as in Fig. 135, the work in this and similar cases may be shortened as follows:—

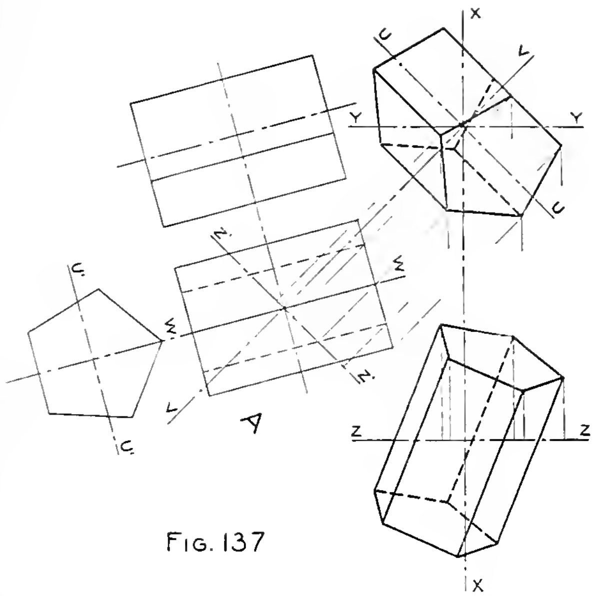


FIG. 137

First locate the C.Ls. X-X, Y-Y, and Z-Z for the required views. Through the center of top view draw U-U at 45° for the H T of a central plane containing the axis, and V-V ⊥ to U-U for the trace of a central plane ⊥ to H and to an aux. plane A || to the axis. Through any convenient point on V-V draw W-W at 60° with U-U as the C.L. of the aux. view, and about the intersection of V-V and W-W construct the aux. view as in Fig. 135. From these aux. views obtain the top view. Observe that this is identical with revolving both front and top views of Fig. 135, through an ∠ of 45°. Project next from H to V, and obtain the distances of pts. above and below Z-Z by measuring from Z′-Z′, regarded as the trace of the hor. central plane Z-Z upon the aux. plane. Connect the proper pts. to complete the front view.

74. Rules Governing the Position of Lines and Surfaces Relative to Any Two Perpendicular Planes of Projection.

(1) A line ⊥ to a plane is || to the ⊥ plane. Its view upon the first is a pt.; its view upon the second is a line || and equal to the line itself and ⊥ to the trace of those planes.

(2) A line oblique to one plane and || to a ⊥ plane has its view upon the first a line shorter than the line itself and || to the trace of those planes; the ∠ the other view makes with the trace is equal to the ∠ the line itself makes with the first plane.

(3) A line oblique to two ⊥ planes has its views upon both shorter than the line itself and neither view shows the true length, nor true ∠s the line itself makes with those planes.

(4) The views of || lines are || unless their views coincide, or are merely pts.

(5) A surface || to a plane is ⊥ to the ⊥ plane. Its view upon the first plane is a figure similar and equal to the surface itself. Its other view is a line || to the trace of the planes.

(6) A surface oblique to one plane and ⊥ to the ⊥ plane is foreshortened || to the trace in its view upon the first. The ∠ the other view makes with the trace of those planes is equal to the ∠ the surface itself makes with the first plane.

(7) The views of || and equal surfaces whose corresponding lines are || are similar figures whose corresponding lines are equal and ||, unless the views coincide, or are merely lines.

(8) If a line or figure be revolved from one position to another about an axis ⊥ to a plane, its view upon that plane remains unchanged in form and dimensions. In the view upon a ⊥ plane the distances of the pts. from the trace of the planes also remain unchanged.

CHAPTER VI

PLANE SECTIONS

75. Principles and Methods. If a plane be imagined to intersect an object, the portion of the object lying within it is called a *plane section*, and the plane a *cutting* or *section plane*, denoted by C. P.

(a) If the portion of the object hiding the section be imagined as removed, the view of the remaining portion or merely that of the section itself, upon a plane || to the C. P., is called a *sectional view*. A sectional view thus shows the sec. in its true shape. Such views are made in place of or in addition to external views to show the form, dimension, and arrangement of hidden parts more clearly; to aid in determining the views of irregular, oblique, and intersecting forms; and to enable the draftsman to dispense with numerous dotted lines.

The figures of this chapter show secs. of geometric forms; practical applications are shown in Chap. XI.

(b) When a sec. is not || to V, H, or P, its true shape may be found by projecting upon an aux. plane || to the C. P., as in Art. 69; or by revolving the sec. || to V, H, or P, as in Art. 70.

(c) The position of a C. P. is indicated in the view in which it is seen edgewise; that is, by its trace upon V, H, or P.

The section is generally indicated by drawing ||s across it called *section lines*, usually at 45° up to the right. The spacing is dependent upon the size and shape of the sec., usually $\frac{1}{16}''$, judged by eye.

Avoid drawing the lines || to the main lines of a sec.

When a drawing is to be inked, it is not desirable to pencil the sec. lines, but the sectioned portion may be indicated by a few lines sketched freehand. In views which show the true shape only, sec. lines may, for economy of time, be omitted.

(d) In obtaining a sectional view the trace of the C. P. is first drawn. This determines the pts. in which the C. P. cuts the edges, elements, or other lines of the object. Next project these pts. to the corresponding lines in the other views, and join them. Then proceed as in (b).

76. Objects Having Plane Surfaces. As the intersection of plane surfaces is a st. line, it follows that any plane sec. of an object bounded by plane surfaces, as a prism or pyramid, will be a polygon of 3, 4, or more sides according as the plane cuts 3, 4, or more surfaces.

(a) A Prism. Fig. 138(a) represents a right square prism with its lateral faces at 45° with V, cut by a plane A-B, ⊥ to its base and || to V. The pts. of intersection 1, 2, 3, and 4 with the top and bottom edges are, therefore, determined in the top view and then projected to the front. As the plane cuts four ⊥ faces, the sec. is a rectangle; and, being || to V, is shown in its true shape in the front view.

Fig. (b) represents the prism in the same position, cut by a plane ⊥ to V, but oblique to H and P. The pts. of intersection are, therefore, determined in the front view.

Fig. (c) represents the prism with its vert. faces at 30° and 60° with V, cut by a plane ⊥ to P and oblique to V and H. This illustrates a case in which the sec. is not symmetrical with respect to a C. L.

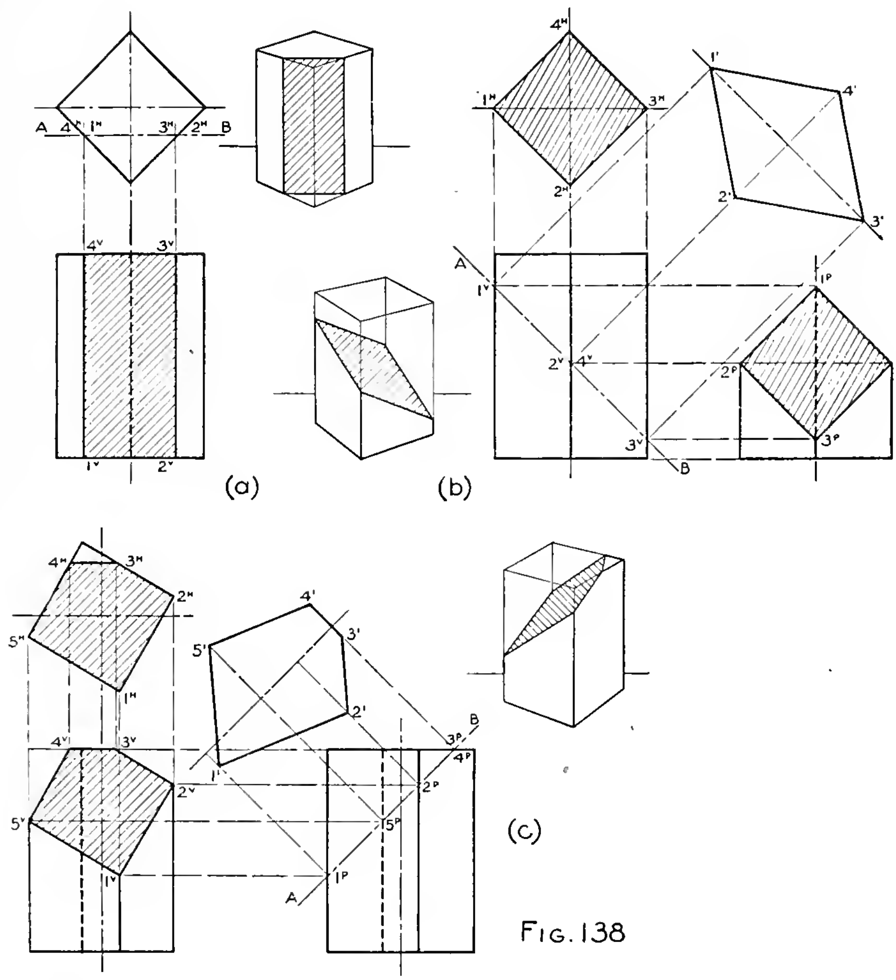


FIG. 138

(b) A PYRAMID. In Fig. 139 the C. P., D-E, cuts the lateral edges of the pyramid at 1, 2, 3, and 4. Pts. 1 and 3 may be projected to the top view in the usual manner; pts. 2 and 4, however, are in edges which are represented by vert. lines in both views. To obtain these pts. in the top view either of the following methods may be used.

First Method. Draw a side view and transfer the distance 2^P-4^P from it to the top view.

Second Method. Imagine the edge A-B to be revolved $\parallel$ to V to coincide with A-C. Then the front view of 2 will be at $2'$ and its top view at $2''$. If now the line A-B be revolved back to its original position, 2^H will be determined as shown; 4^H may in like manner be found.

The C. P., F-G, gives a triangular sec. The method of finding pt. 7^V is evident from the preceding.

77. Objects Having Curved Surfaces.

(a) A Sphere. Any sec. of a sphere is a $\odot$ whose center is in the diam. of the sphere, $\perp$ to the C. P. See Art. 2(n).

In Fig. 140 the top view of sec. on A-B is thus a $\odot$ whose diam. is equal to 1^V-2^V. The front view of sec. on C-D is an ellipse. The intersection of the

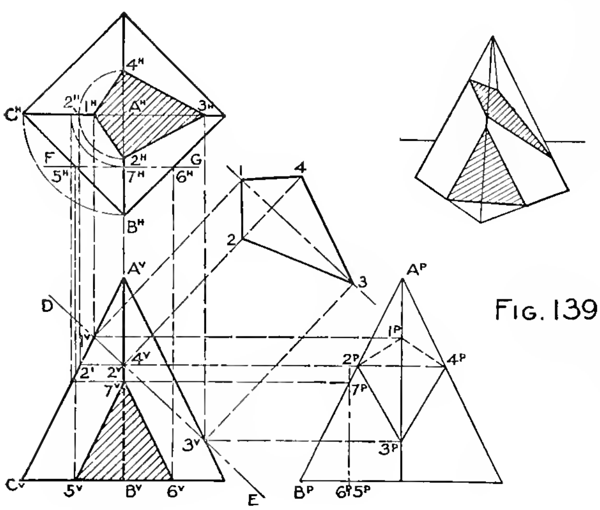


Fig. 139

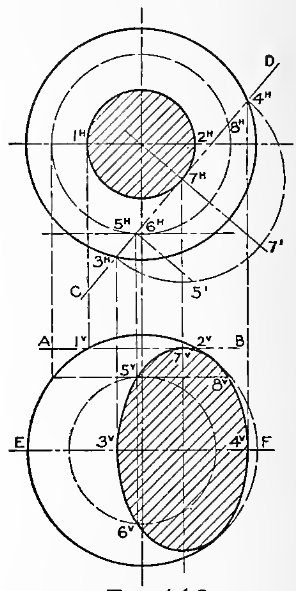


Fig. 140

C. P. with the hor. great $\odot$ of the sphere determines 3 and 4 in the top view. As the front view of that $\odot$ is in the hor. E-F, these pts. will be projected at 3^V and 4^V, as shown. Intermediate pts. of the curve may be found by determining pts. of intersection of the C. P. with other $\odot$s of the sphere whose planes are $\parallel$ to either H or V. Thus, assuming a $\odot$ parallel to V, cutting the $\odot$ of the sec. at 5 and 6, these points will be determined in the top view and projected at 5^V and 6^V in the front. Again, assuming a hor. $\odot$ to cut the sec. at 5 and 8, these pts. will be determined in the top view, and projected at 5^V and 8^V. Note that the highest pt., 7, of the curve is that in which a hor. $\odot$ becomes tangent to the plane of the sec.

The assumed $\odot$s may be regarded as lines of intersection given by aux. C. Ps., each of which cuts the plane of the sec. in a chord of both $\odot$s, as 5-6, whose end pts. are thus in the required curve.

The intermediate pts. of sec. C-D may also be found by the reverse of the method of Art. 70. Thus the half sec. revolved || to H about diam. 3-4 determines the distance of pts. 5 and 6 from diam. 3-4, to be set off above and below that line in the front view.

(b) A CYLINDER. Any sec. || to the axis of a right circular cylinder is a rectangle, and a sec. || to the base, a ⊙. See Art. 2(l).

The sec. on A-B (Fig. 141) is an ellipse whose top view is a ⊙ coinciding with the view of the base. The sectional view may be obtained as in Art. 69(e), or by determining pts. of intersection of the C. P. with elements, as indicated.

The assumed elements may be regarded as lines of intersection given by aux. C. Ps. which cut the plane of the sec. in lines, as 2-6 and 3-5, whose ends are thus in the required curve.

(c) A CONE. A sec. through the vertex and base of a right circular cone is a △; a sec. ⊥ to the axis, a ⊙ whose center is in the axis of the cone. See Art. 2(m).

The oblique sec. (Fig. 142) is an ellipse, pts. for the top and sectional views of which may be obtained by determining the pts. of intersection with elements of the cone. A more accurate method is to assume a number of ⊙s of the cone to cut the sec. These will be || hors. in the front view and ⊙s concentric with the ⊙ of the base in the top. Thus, drawing the front view of a ⊙ through any pt., as 1^V, 3^V, and projecting from 1^V, 3^V, to the top view of the ⊙, pts. 1^H and 3^H will be determined.

The vert. sec. being ⊥ to both V and H has both front and top views a st. line, but being || to P will show its true shape, a hyperbola, on that plane.

The C. P. cuts the right element at 2 and the ⊙ of the base at 4 and 5, which pts. may be obtained in the sectional view in the usual manner. Intermediate pts. may be obtained by use of elements, but it is more accurate to assume other ⊙s of the cone, to intersect the sec. Thus a ⊙ cutting the sec. at 6 and 7 determines the distances of those pts. from the C. L. in the top view.

The assumed elements and ⊙s may be regarded as lines given by aux. C. Ps., as in the case of the cylinder, Art. (b).

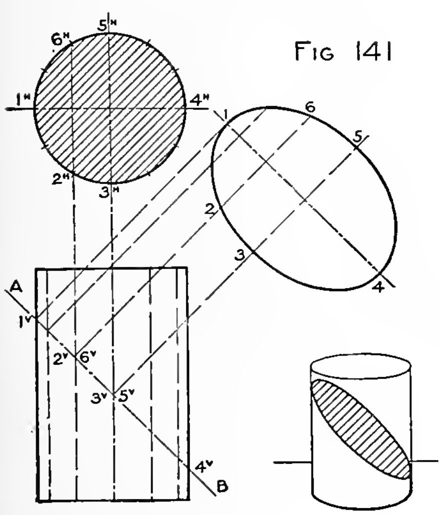


FIG 141

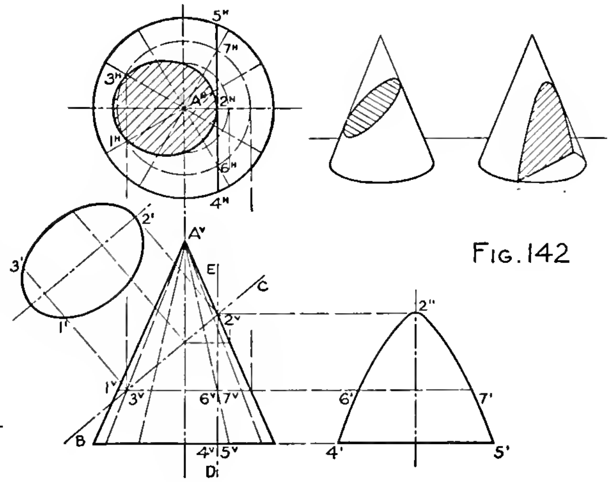


FIG. 142

CHAPTER VII

INTERSECTION OF SURFACES

78. Principles and Methods. The line or lines in which the surface of one integral part of an object intersects that of another part is called a *line of intersection.* This line joins the pts. in which the edges, elements, or other lines of each part meet the surface of the other, as is evident from Figs. 144(a), 145(a). The problem, therefore, in determining the line of intersection is to find the pts. of intersection of the edges, or of a sufficient number of other lines, with the surfaces, and to draw the line through the pts. thus found.

(a) The pt. of intersection of a line and a surface is determined in the view in which the surface is seen edgewise or as a line, and then projected to the other view of the line precisely as in finding the pts. of a plane section.

Thus, in Fig. 143, line A-B intersects the front face of the object at 1, as determined in the side view, for if it be assumed to intersect the left side face, pt. C would be seen in the side view to come above the object. A-B also intersects the right side face at 2, as determined in the front view.

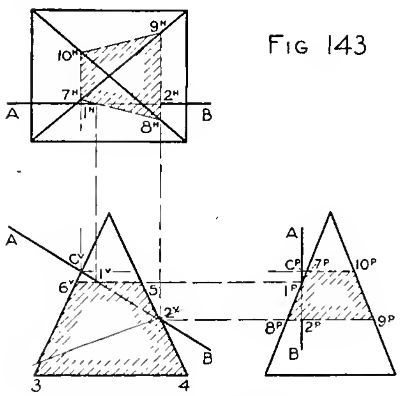


FIG 143

When the intersected surface is not shown as a line in either of the required views, an aux. view which will so represent it may sometimes be used. The pt. of intersection of any line and surface may be determined by passing a plane through the line, ⊥ to the plane of either of its views. This C. P. cuts the given surface in a line in which the required pt. of intersection must lie, for both lines are in the same plane.

Thus, in Fig. 143, a plane ⊥ to H and P gives a sec. 3 4 5 6, and as the lines of the sec. are in the surface of the pyramid, pts. 1 and 2, in which A-B intersects them, must be the required pts. Similarly a plane ⊥ to V, gives sec. 7 8 9 10, by which 1 and 2 are determined in the top, or side view.

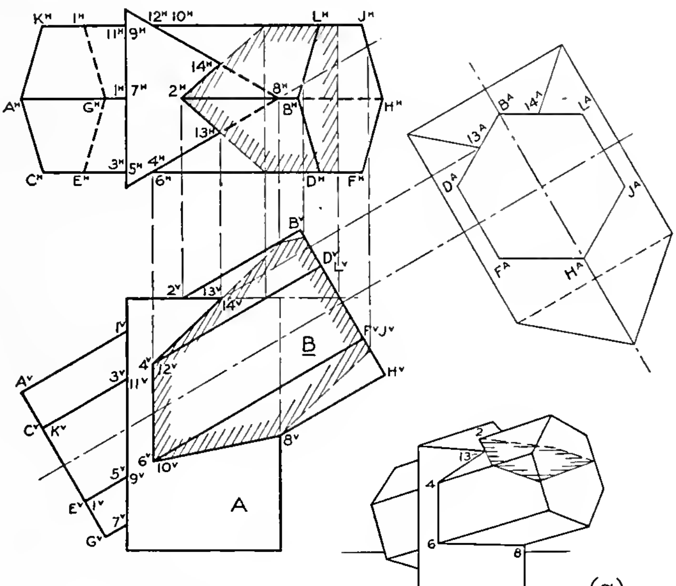
(b) It is evident that a plane which cuts both intersecting parts of an object would give a plane sec. of each, and the pts., if any, in which the lines of these secs. intersect, being in the surfaces of both parts, must be pts. in the required line of intersection. By assuming a series of such C. Ps., any desired number of pts. may be found.

The position of the C. P. should, when possible, be so chosen that the sec. of each part is one readily obtained.

(c) In problems involving intersections, first draw each part as complete as possible in itself, that is, without regard to its intersection. Next obtain the

pts. of intersection of the edges or elements which can be directly determined in either of the views; then those whose pts. must be found by means of C. Ps., or aux. views. In finishing, only such lines should be rendered as edges or outlines as represent the edges or outlines of the object as a whole.

79. Objects Having Plane Surfaces. Fig. 144 represents the intersection of a triangular prism (A) and an oblique hexagonal prism (B). The lateral edges, A-B, C-D, E-F, etc., of (B) intersect the left vert. surface of (A) at 1, 3, 5, 7, 9, 11. As this surface is seen as a line upon both V and H, the pts. are determined in both views, and since all the pts. lie in the same plane as that of the surface, the line of intersection is simply the outline of a plane sec. of (B). In this case it is an irregular hexagon which would be seen in a side view.



(a)

FIG. 144

The edge A-B intersects the upper surface of (A) also at 2. As the surface is seen as a surface upon H and as a line upon V, pt. 2 is determined in the front view and then projected to the top. Edges C-D, E-F, I-J, and K-L intersect the front and rear surfaces of (A) also, at 4, 6, 10, and 12, respectively. As these surfaces are seen as lines upon H, the pts. are there determined and then projected to the front view. Edge G-H and the right vert. edge of (A) are in the same plane || to V and thus seen to intersect in the front view at 8.

Points 13 and 14 in which the hor. edges of (A) intersect the surfaces of (B) are not directly determined in either view, for neither of the intersected surfaces is there seen as a line. By obtaining an aux. view upon a plane $\perp$ to the axis of the oblique prism, the intersected surfaces of the latter will be seen as lines D^A-B^A and B^A-L^A and the pts. of intersection of the edges of (A) determined at 13^A and 14^A as shown. These pts. may then be projected to the front view. It is obviously unnecessary to draw the complete aux. view.

When the preceding method is not convenient or possible, the pts. may be found by means of a C. P.; thus, if the plane of the hor. surface containing the edges be assumed to intersect (B) it would give a sec., the intersections of whose sides with the edges of the hor. surface determine 13 and 14 in the top view as shown. Again, if the plane of the front surface of (A) be assumed to intersect (B) it will give a sec., the intersection of a side of which with the front hor. edge

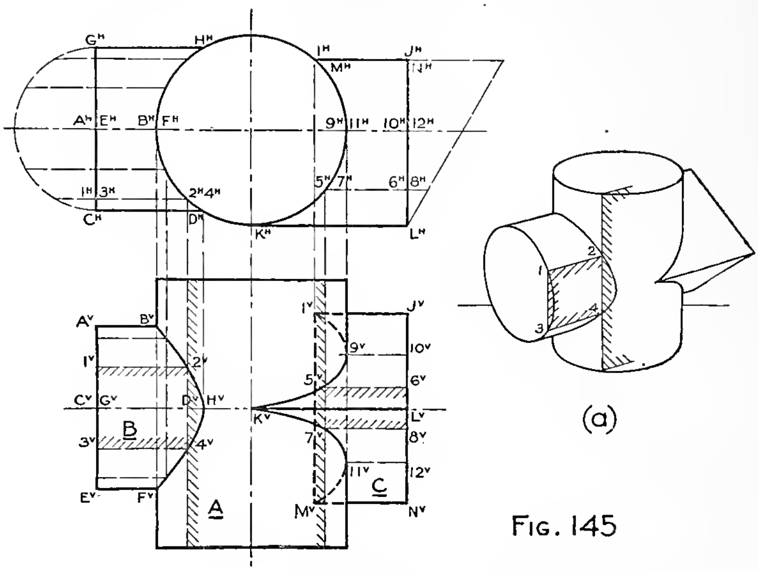


FIG. 145

of (A) determines pt. 13 in the front view. Pt. 14 could in like manner be found. It is evident that merely those lines or portions of the secs. which determine the required pts. need be drawn.

80. Objects Having Curved Surfaces.

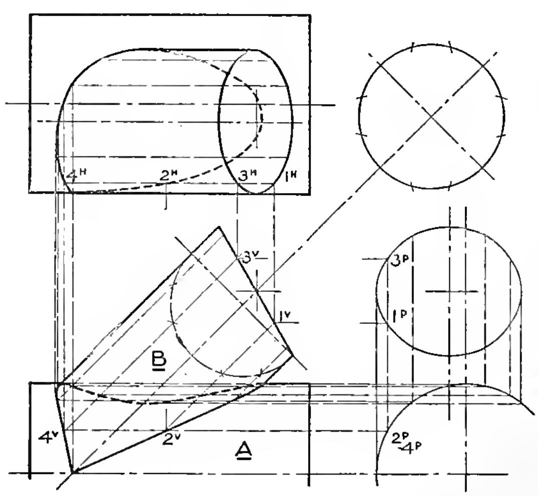


FIG. 146

(a) Fig. 145 represents the intersection of two circular cylinders (A) and (B) and an equilateral triangular prism (C). The line of intersection of (A) and (B) is determined by the pts. of intersection of the elements of one cylinder with the surface of the other. Thus B, D, F, and H in which the upper, front, lower, and rear elements of (B) intersect (A) are determined in the top view, for the cylindric surface of (A) is there seen as a line (circle).

Intermediate pts. may be found by assuming intermediate elements of (A) in a side view, or of (B) as shown; the positions of the elements

of the latter being transferred from top to front view by means of the revolved half-base, Art. 73.

Note also that C. Ps. || to the axes of the cylinders would cut elements of both, which intersect in pts. of the required curve.

The views of prism (C) may be determined by means of a side view, or a revolved half-base as shown. The pts. of intersection of the hor. edges with cylinder (A) are determined in the top view. Note that the rear surface intersects the cylinder in an element. The inclined surfaces intersect (A) in elliptic curves, intermediate points in which may be found by assuming elements of the cylinder and determining their intersection with (C) in a side view; or by assuming lines upon the prism || to its axis. Thus a hor., 5-6, intersects the cylinder at 5, determined in the top view.

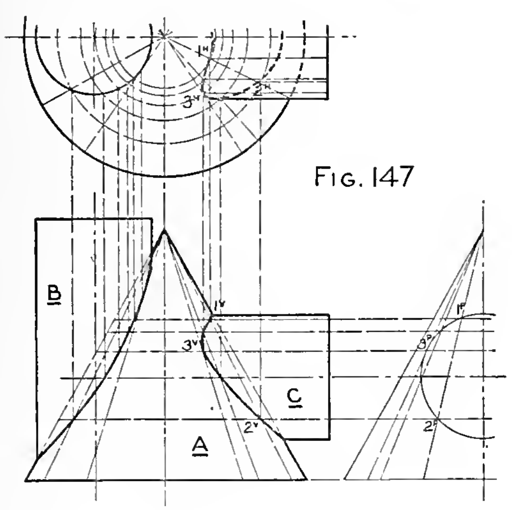


FIG. 147

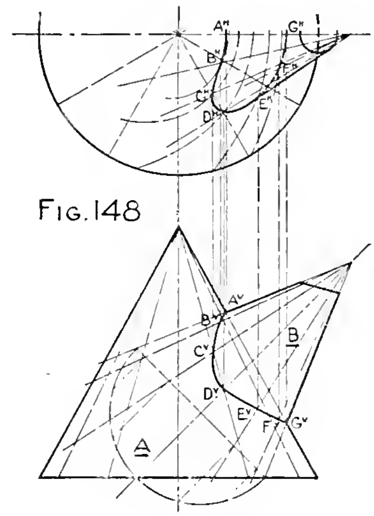


FIG. 148

Again, a C. P. || to the axes of (A) and (C) would give an element of (A) and two lines of (C) whose pts. of intersection must be in the required curves as shown. Note that pts. 9 and 11, in which the direction of curvature changes, are at the intersection of lines 9-10 and 11-12 with the right element of (A).

(b) In determining the curve of intersection of cylinders (A) and (B) in Fig. 146, the same methods would be used as in (A) and (B) of Fig. 145.

Equidistant elements of (B) may be determined by an oblique aux. view, or a revolved half-sec. taken ⊥ to the axis, as shown.

(c) In determining the intersections in Fig. 147, the C. Ps. may be taken horizontally, or through elements, as shown. If cylinder (c) were oblique, an oblique aux. view could be used.

(d) The simplest method of determining the intersection in Fig. 148 is to pass C. Ps. through the elements of (B). The secs. of (B) will thus be △s and those of (A) ellipses, or other curves.

(e) Fig. 149 represents a form similar to the stub end of a connecting rod. The highest pts., B and D, of the curves, in which the bell-shaped neck of the

cylindric portion intersects the rectangular, are directly determined in the front and side views, and will be seen from the plan to be the pts. in which circular secs. become tangent to the sides of rectangular secs. The lowest pts., A, C, E, and F, lie in the ⊙ through the corners of the rectangle and, therefore, located in the front and side views by projecting from the plan to the corresponding views of that ⊙, which are obtained as shown.

Other pts. are determined by intermediate C. Ps. Thus plane G-H gives a ⊙ which cuts the rectangle at 1, 2, 3, and 4 of the required curve, which are located in the other views as in the preceding.

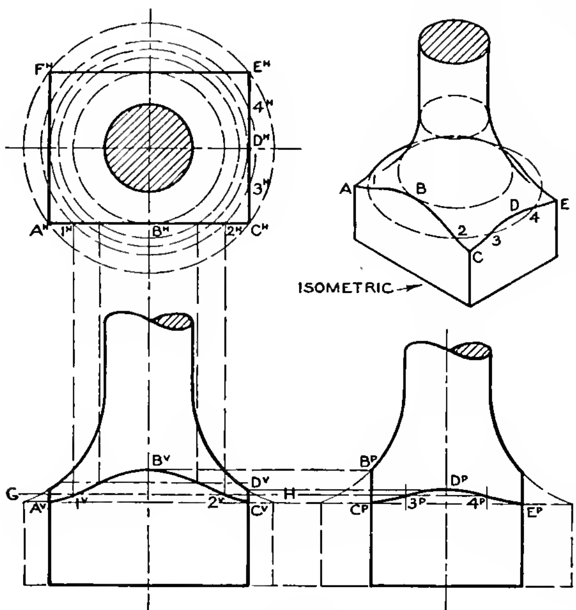


FIG. 149

CHAPTER VIII

DEVELOPMENT OF SURFACES

81. Principles and Methods. *A development* is the representation of the surfaces of an object as laid out, unfolded, or unrolled into the plane of the drawing. The operation is suggested pictorially by Figs. 150 (a), (b). A development thus shows the exact area of all surfaces of the object and the exact length of every line of those surfaces, Fig. 151. Plane, cylindric, and conic surfaces only can thus be developed. Surfaces of double curvature and warped surfaces may be developed approximately by assuming portions to be cylindric, conic, or triangular.

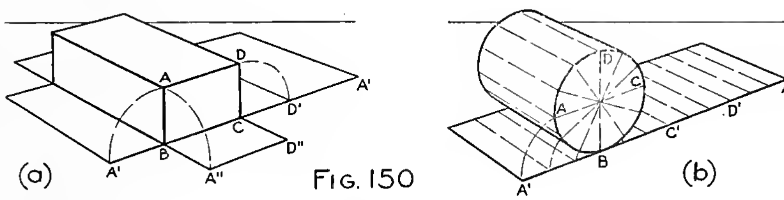


Fig. 150

Developments are made to determine the shapes of surface patterns required in constructing objects of sheet metal, cardboard, etc.; to plot groove outlines for cylindric cams; and to obtain templets or patterns for irregular surfaces, etc.

(a) To OBTAIN A DEVELOPMENT. First draw the views from which the measurements of the lines can be made. The surface may be imagined as opened on any lines but its different parts should, so far as practicable, be represented as attached to each other,—each being so placed that if the dev. were cut out upon its outer line and properly bent, it would form or envelope the object, surface for surface, line for line.

In obtaining lengths from the views, transfer the measurements with dividers.

Remember that a line shows its true length only upon a plane to which it is ||. If not thus shown, its true length must first be determined. The dev. may be placed in any convenient position. In some cases it is possible to place it so that one set of dimensions may be projected, as in Fig. 151. It is sometimes desirable to attach it to some line or lines of a view (Figs. 154, 159-161), practically as revolved about those lines.

(b) The reproduction of forms in thick paper, by cutting and bending devs., will prove an excellent aid to correct solutions. The surfaces may be held in position by providing paste laps (see Fig. 151) or by using gummed binding. To obtain neat edges the folding lines should be lightly scored with a sharp-pointed knife.

(c) In practical work, allowance must be made for seams, laps, thickness of material, etc. Economy in cutting is also important.

Material for double curved, or warped surfaces, is cut to patterns of assumed cylindric, conic, or triangular portions and then beaten, pressed, or stretched to the required form. In some cases the material is stamped by dies, or spun to form in a lathe.

82. Objects Having Plane Surfaces.

(a) PRISMS. The dev. of a right prism consists of two similar polygons for the bases and as many rectangles as the prism has sides. In obtaining the dev. of the hexagonal prism (Fig. 151), observe that the lateral edges are || to V, and the base edges to H. The front and rear base edges are also || to V.

First set off the true lengths of the lower base edges upon a line, A-A. At pts. A, B, C, etc., draw ⊥s. Upon these set off the lengths of the vert. edges and connect the pts. to complete the lateral surface. Attach the bases to any side.

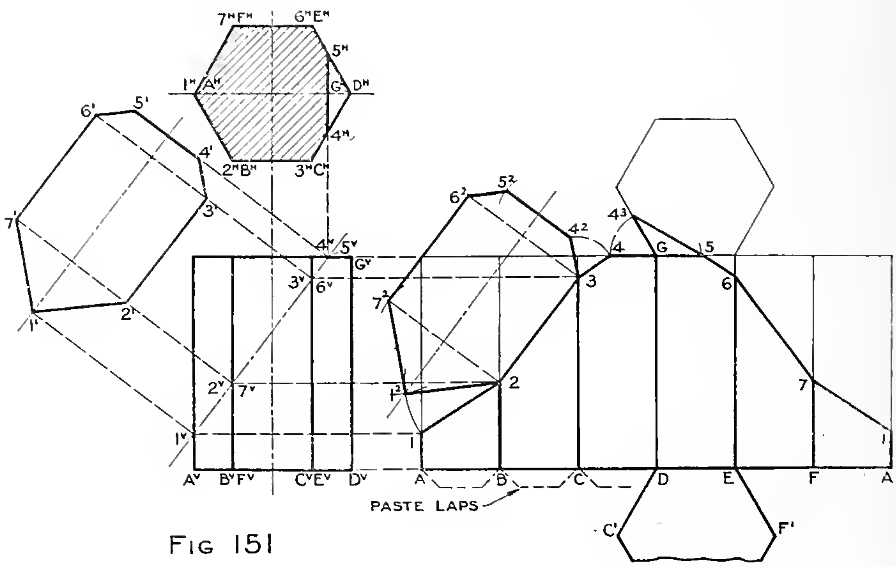


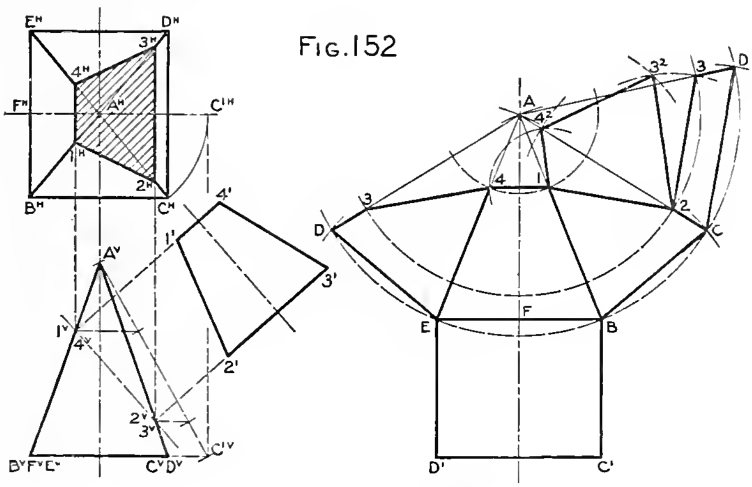
FIG 151

To develop the prism after the portion above an oblique C. P. 1-4, has been removed, obtain base line A-A, lower base, and ⊥s as in preceding. Now assuming the surface to be opened from edge A-1, this edge will be the outer verts. A-1, in the development. Beginning with A-1, transfer the lengths of the verts. to the corresponding lines in the dev. Similarly transfer lengths of base edges G-4 and G-5 to the hor. through G. The lines joining 1, 2, 3, 4, and 5, 6, 7, 1 will be the dev. of the line of intersection of the C. P. with the lateral surface, and must, therefore, agree in length with the corresponding lines of the sectional view. Such lines should always be compared with dividers. The method of obtaining the portion G4^{3}5 of the upper base is evident. To complete the dev., draw a figure similar and equal to the true shape of the oblique surface by Art. 56, attaching it to any side, as B C 3 2.

(b) PYRAMIDS. The dev. of a right pyramid consists of a polygon for the base and as many △s as the pyramid has sides. The slant edges of the rectangular pyramid (Fig. 152) are equal, but are not projected in their true length in either view. Assuming the surface to be opened from one of these, obtain its true length as in Art. 71, and with this as rad., describe an indefinite arc DEBCD. Upon the arc set off the successive lengths of the base edges. Join these pts. and each to the center A, the vertex, to complete the lateral surface. Then attach the base. Or, lay off first one side of the base as E-B, and with E and B as centers and the true length of the slant edges as rad., describe arcs to intersect at A; then proceed as in preceding.

Since the altitude of each side is ⊥ to a base edge, the vertex A could be determined by setting off the true length of an altitude, as A-F, ⊥ to its corresponding base edge E-B, as indicated.

In pyramids whose inclined edges are not equal, it is necessary to obtain the true length of each separately, and to construct the △s by Art. 37, joining them on their common sides.



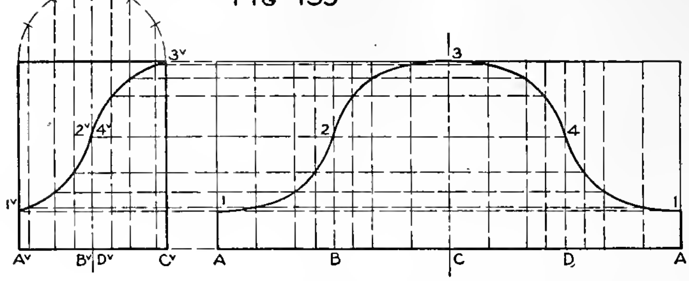
To develop the pyramid (Fig. 152) when truncated, first obtain dev. of entire pyramid. Then obtain the true distances of pts. 1, 2, 3, and 4, from the vertex, or base (Art. 71). Set off these distances upon the corresponding lines in the dev. and join the pts. thus found to complete the sides. Finally, copy the true shape of the top surface from the sectional view, attaching it to any side, as B C 2 1.

83. Objects Having Cylindric or Conic Surfaces.

(a) CYLINDERS. Since the elements of a right circular cylinder are equal and ⊥ to the bases, the dev. of the curved surface (Fig. 153) will be a rectangle whose height is equal to the length of the elements, and base equal to the length of the circumference.

The length of the base edge may be obtained as in Art. 32, and laid off

FIG 153



upon a line A-A. At the ends of this line draw ⊥s and complete the rectangle. As each of the bases would touch the dev. of the curved surface at but one pt., it is not necessary to attach them.

To develop the curved surface when cut off on line 1 2 3 4 1, obtain base line A-A, divide it into 12 or 24 equal parts according to the number of elements assumed upon the cylinder, and through the pts. draw ⊥s. The length of the cut elements may then be transferred from the front view as in the case of the edges of a prism. The curve traced through 1, 2, 3, 4, 1 will complete the lateral surface. See Art. 18(a).

When, as in (B) Fig. 159, neither end is a ⊙, both will develop as curves. It is necessary, therefore, to assume some ⊙ of the surface whose development

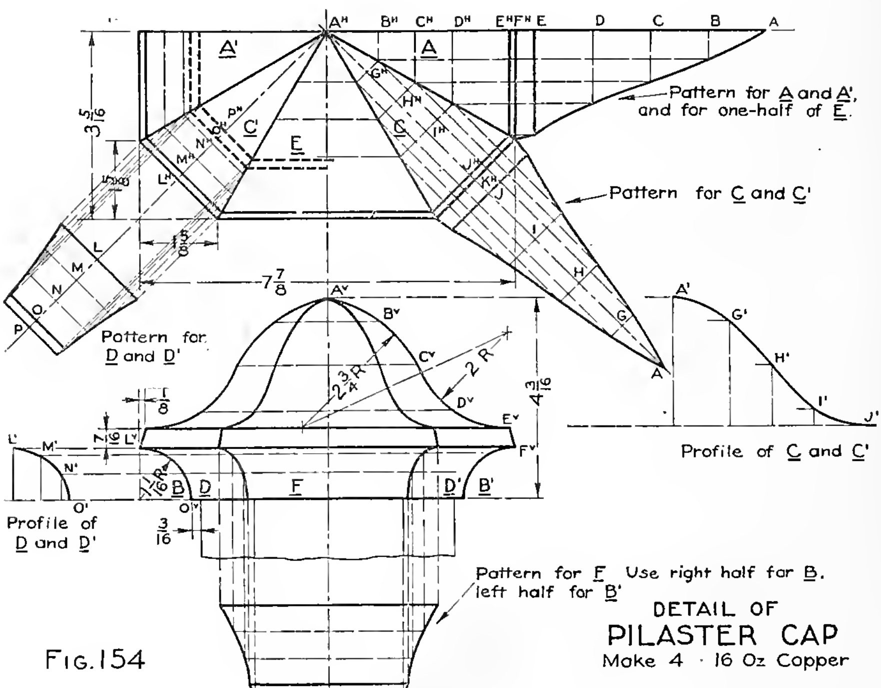


FIG. 154

may be used as a base line upon which to set off the true distances between the elements and from which to set off their lengths. Such line may be obtained by a C. P., a-E^V, taken $\perp$ to the elements as shown. See also Fig. 160.

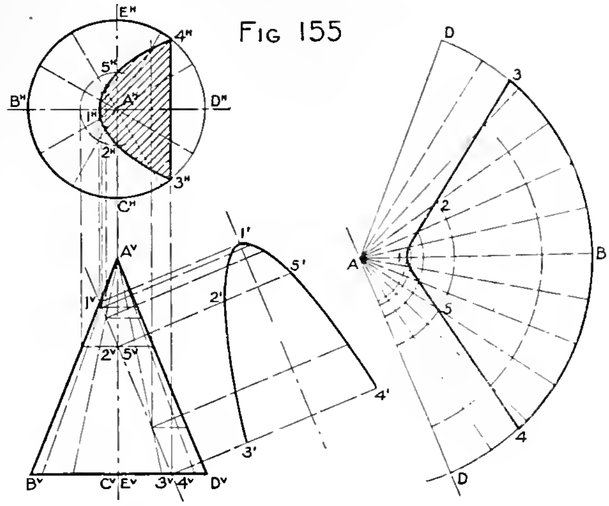


FIG 155

Fig. 154 illustrates the dev. of an object with cylindric curved sides. The true distances between the elements of surfaces (A) and (B) are determined upon A-E and L-O in the elevation and their lengths in the plan. The distances between the elements of (E) and (F) are identical with those of (A) and (B). To determine the true distances between the elements of (C) and (D) it is necessary, since these elements are not $\perp$ to V, H, or P, to obtain the profiles of (C) and (D) by aux. views or secs. upon planes $\perp$ to the elements, as indicated.

(b) CONES. Since the elements of a right circular cone are of equal length, the dev. of the curved surface (Fig. 155) will be a sector whose radial sides, A-D, are equal to the true length of an element and whose arc, D-D, equals the length of the circumference of the base. To determine the length of this arc, obtain $\frac{1}{12}$ or $\frac{1}{24}$ of the base circumference and set it off 12 or 24 times in the dev.

To develop the portion below the parabolic sec., obtain the base arc D-D, divide it into 12 or 24 equal parts according to the number of elements assumed upon the cone and draw the elements. Then find their lengths when cut off, as in the case of the pyramid, Art. 82(b).

Since the left element is || to V, the true distance of pt. 1 from the vertex A is seen in the front view. The true distances from A of intermediate pts., as 2 and 5, are not seen in either view, but as the elements of the cone are equal, hors. from these pts. to A-B will determine upon the latter the required distances. (See Art. 71(b).) Having transferred these to corresponding elements in the dev., trace the curve through them.

The method of developing a right circular conic surface whose ends are not in planes $\perp$ to its axis is evident from Fig. 161(b).

In a conic surface other than right circular as in Fig. 156, or one whose vertex is inaccessible as in Fig. 161, it is necessary to assume the surface to be composed of plane $\triangle$s whose sides are elements and whose bases are short chords of the base of the cone. The method, called *development by triangulation,* is thus identical with that used in developing a pyramid with unequal slant edges. Art. 82(b).

To develop the oblique elliptic cone (Fig. 156) obtain equidistant elements as shown. Assuming the surface to be opened upon A-D, the line A-B will be the

C. L. of the dev. and may be drawn directly at A′-B′, equal to its true length A^V-B^V. The true lengths of elements A-1, A-2, etc., may be found by revolving them || to V. To avoid confusing the views, however, a separate diagram of true lengths may be constructed. The true length of any element will be the hypotenuse of a right △ whose base is equal to the length of that element in the plan and its altitude equal to the vert. height of one end pt. above the other in the ele-

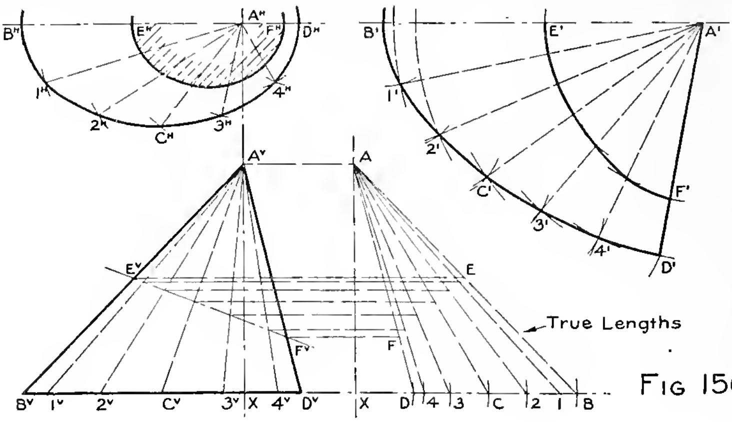


FIG 156

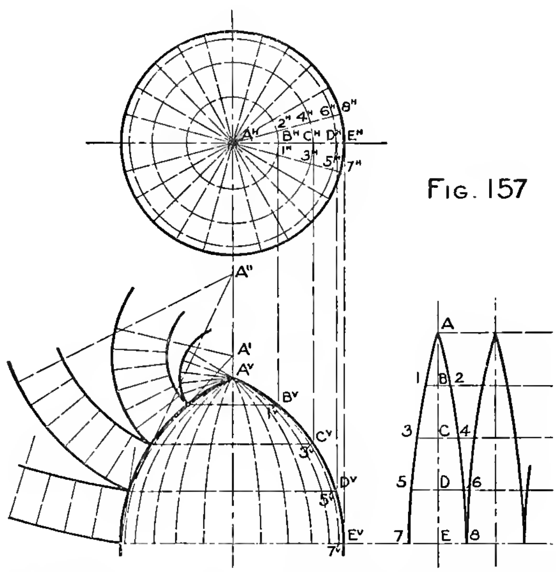


FIG. 157

vation. Hence, draw A-X ⊥ to the base line and equal to the altitude of the cone; then lay off X-1, X-2, etc., equal to A^H-1^H, A^H-2^H, etc., and connect pts. 1, 2, etc., to A. Observe that this is equivalent to revolving the elements || to P. Now with A′ as center and rad. A-1 draw an arc across A′-B′; with B′ as center and rad. B^H-1^H intersect this arc at 1′. Then A′-1′ will be the developed position of A-1. Continue this operation until all elements have been determined and trace the curve B′1′2′, etc., through the base pts. as indicated.

The figure also illustrates the method of developing the cone when truncated.

84. Objects Having Double Curved, or Warped Surfaces.

(a) Fig. 157 illustrates the method of developing a double curved surface by assuming portions, as A 7 8, to be cylindric, also by assuming portions between the ⊙s to be conic.

Fig. 158 illustrates a transition piece of piping, A, whose surface is warped, being neither cylindric nor conic. Such surfaces can be developed approximately only, by triangulation. Art. 83(b).

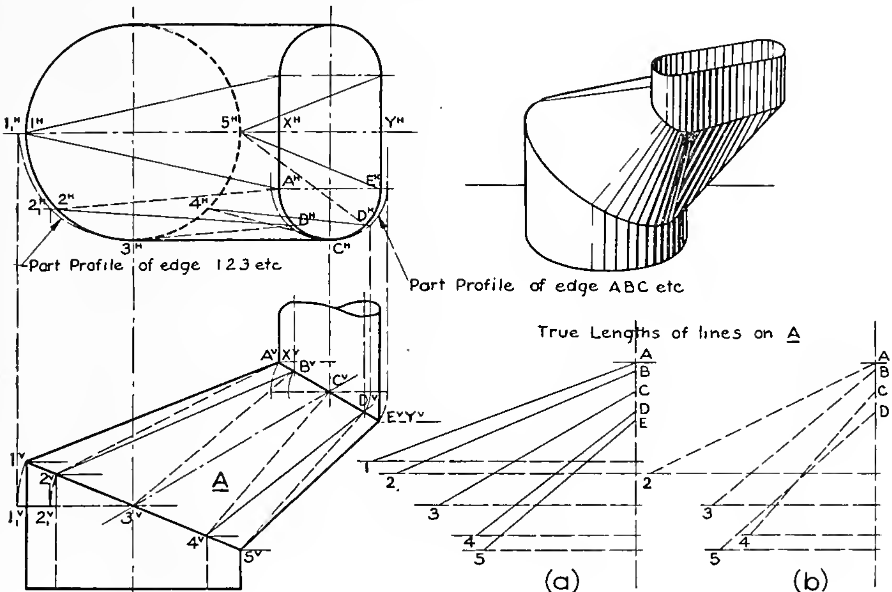
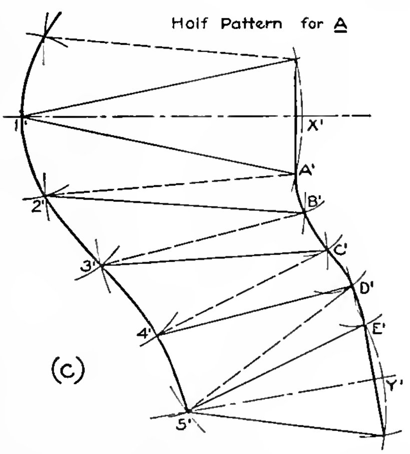


FIG 158



The surface may be divided into measurable △s as shown. In the plan divide half of the base and curved end of the top edge into the same number of equal parts, at least six. Observe that as the planes of both edges are oblique to H, each must first be revolved || to H, or V, and then back to its oblique position. Join the corresponding pts. in each with full lines 1-A, 2-B, etc.; also draw lines 2-A, 3-B, etc., dotted for contrast.

Next construct the diagram (a) for the true lengths of the full lines, noting that neither the upper nor lower pts. are on the same levels. Similarly construct diagram (b) of true lengths for the dotted lines.

As the surface is symmetrical about the C. L. 1-Y, the line 1-X may be drawn directly at 1′-X′ in the dev. (c), equal to its true length 1^V-X^V. With 1′ as

center and rad. 1-A of diagram (a) describe an arc across 1′-X′. With X′ as center and rad. X-A of the plan, intersect this arc at A′. Then 1′-A′ will be the developed position of line 1-A. With A′ as center and rad. A-2 of diagram (b), describe an arc. With 1′ as center and rad. 1-2 of the revolved base, intersect this arc at 2′. Then A′-2′ will be the developed position of line A-2.

With 2′ as center and rad. 2-B of diagram (a), describe an arc. With A′ as center and rad. A-B of the revolved top edge, intersect this arc at B′. Then 2′-B′ will be the developed position of 2-B. Continue these operations until all points have been determined and complete the dev. as shown.

85. Intersecting Surfaces. In intersecting parts of an object, the line of intersection being common to both surfaces will be developed in each. As this line is determined by the pts. in which the edges, elements, or other lines

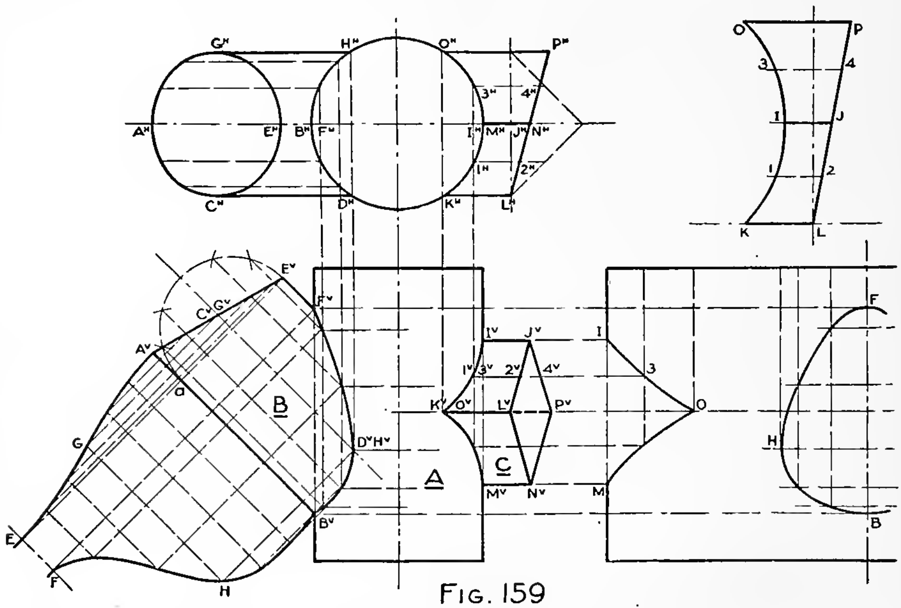


FIG. 159

of each part intersect the surfaces of the other, and the dev. gives the true length of every line of every surface, it follows that these pts. may be found by transferring the true lengths of the lines which determine them in the views, to the corresponding lines drawn in the dev.

(a) The lateral surface of (B) (Fig. 159) is developed as explained in Art. 83(a). The dev. of the rear half only is shown and is attached upon element A-B for convenience in transferring lengths. The distances between the elements are seen in the revolved sec. of a-E^V and transferred to the base line E-a, as shown.

(b) The method of developing the lateral surface of (C) is evident. Lines as 1-2 and 3-4, which give intermediate pts. of the line of intersection, are found by obtaining their true distances from the || edges in the revolved sec., and their true lengths, from either the front or top view. The dev. of the upper half only is shown.

(c) To develop the lateral surface of (A), first obtain the dev. of the entire surface, that is, a rectangle (rear half only is shown). Assume surface to be opened from right element. This element cuts the surface of (C) in I and M. The opposite element cuts the surface of (B) in F and B and will be in the center of the dev. From these elements the positions of the other elements of (A)

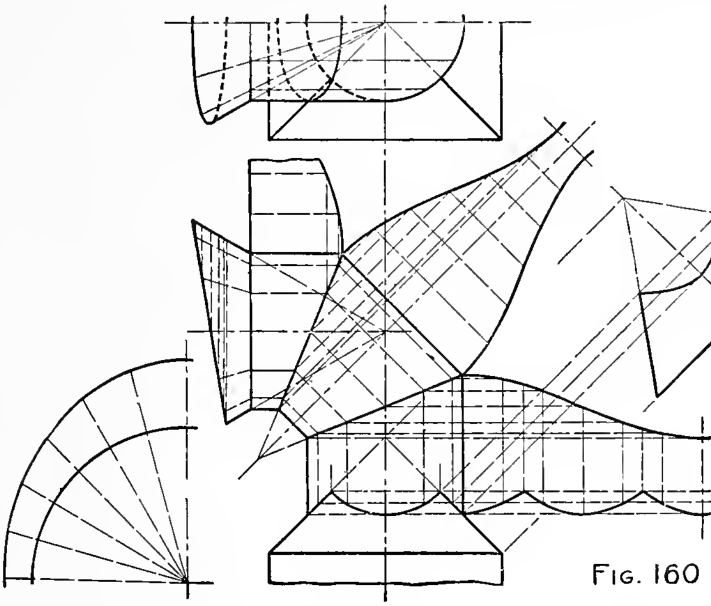


FIG. 160

which cut the surfaces of (B) and (C) may be determined. The distances of these elements from the outer elements are seen in the top view, and the distances of their points of intersection from the bases of (A) are seen in the front view.

(d) Fig. 160 illustrates a pipe elbow with conic and pyramidal flanges; Fig. 161, two other common forms, the methods of developing which are indicated.

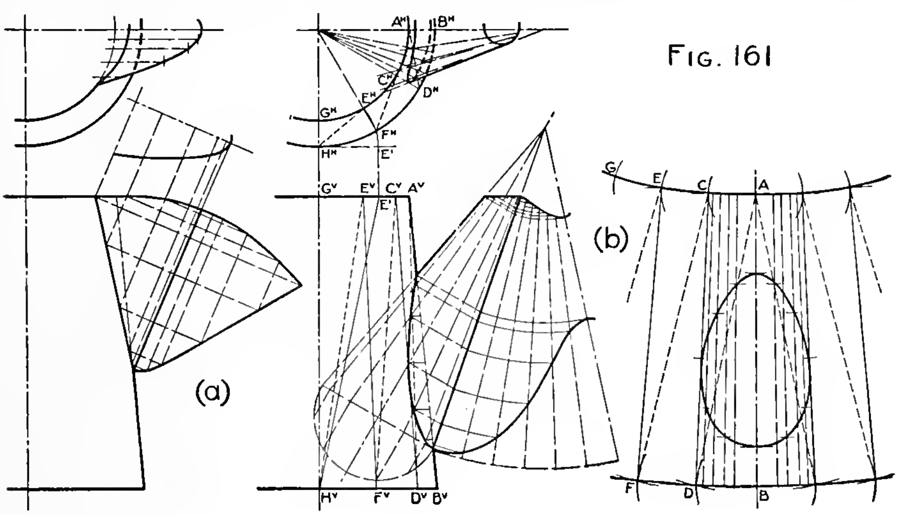


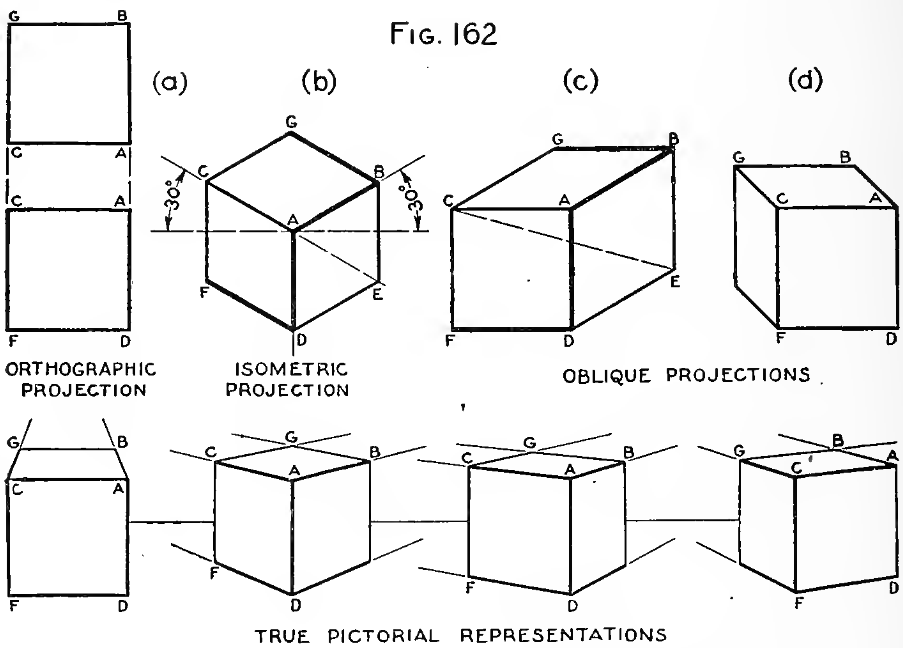
FIG. 161

CHAPTER IX

MECHANICAL PICTORIAL DRAWINGS

86. Character and Purpose of the Drawing. It has been noted that two views at least are required to show the exact form, size, and relation of all lines and surfaces of an object, and that two only of its three dimensions can be shown in their actual proportion and relation in one view. It is sometimes necessary, however, to represent an object or detail by a single oblique view having a more or less pictorial effect, while at the same time showing the relative proportions of its principal lines or dimensions to a scale. Compare Figs. 162 (a), (b), (c), etc.; 163 (a) and (b); 169 (a) and (b).

FIG. 162



Such representations are made in place of or supplementary to the usual views for the purpose of general illustration, or to describe details of machine, furniture, and building construction and assembly more directly and clearly. They are also extensively employed for catalog illustrations and Patent Office drawings.

The methods ordinarily used are those of *Isometric Projection* and *Oblique Projection*, the choice depending upon the form of the object and the particular effect desired to be given. A drawing made by either method is never a true picture, since || lines are always represented by ||s as in orthographic proj.,

while in a true pictorial representation the apparent convergence of receding ||s is shown. Hence, such drawings often give an unsatisfactory effect of distortion.

87. Isometric Projection. If a cube, placed as shown in Fig. 162(a), be turned 45° about a vert. axis, then forward until the diagonal of the cube through A is ⊥ to V, all of the edges will be equally inclined to that plane, and being equal in length their projs. upon it will be equal. Such view is an *isometric* (equal measure) *projection* of the cube. (See Fig. (b).)

When a rectangular object is thus related to the plane of proj., it will be seen that each of its edges will be || to one or another of three mutually ⊥ lines, as A-B, A-C, and A-D, which correspond in direction to the axes or principal dimensions (l, b, and t) of the object. These lines are called the *isometric axes*, and their projs. form equal ∠s of 120° about a pt. A. All lines of the object coinciding with or || to the isometric axes are called *isometric lines;* all others are *non-isometric lines.* The planes determined by the isometric axes and all planes || to these are called *isometric planes.*

Note that isometric lines only, make equal ∠s with the plane of proj.; hence, equal distances upon such lines only will be equally foreshortened in the view.

(a) Instead of obtaining the view by the methods of Art. 72, an isometric is usually constructed by setting off the limiting pts. of the lines directly upon isom. lines and joining the points thus determined. Measurements must never be made upon non-isometric lines. The foreshortening of the isometric lines, which is about .81 of full size, is usually disregarded and the measurements made equal to the true lengths of the corresponding lines of the object, or to some other common scale.

One of the axes is usually assumed as vert.; the others, therefore, are at 30° with the hor. direction, as in Fig. 162(b). When the lower surface of an object is to be visible the axes are reversed. Invisible lines are omitted unless they give necessary information.

When dimensions are given, the dimension and extension lines must be isometric. See Fig. 163.

In general, sections and breaks should be taken in isom. planes. See Figs. 164, 170, 194; also invisible section, Fig. 165.

88. To draw the isometric of a rectangular object.

(a) A Cube. Fig. 162(b). From any pt., as A, draw indefinite lines A-B and A-C at 30° and a vert. A-D. Upon these set off the given dimensions of the object to the desired scale. Since each edge is || to one or another of the isom. axes, it will be || to the corresponding line in the drawing, and the representation may be completed as shown. It is evident that the isom. could be started from any assumed pt., as D or E.

(b) An Object with Rectangular Details. Fig. 163. Starting at any pt., as A, draw the isom. of the bottom board (A), obtaining all measurements from the front and top views.

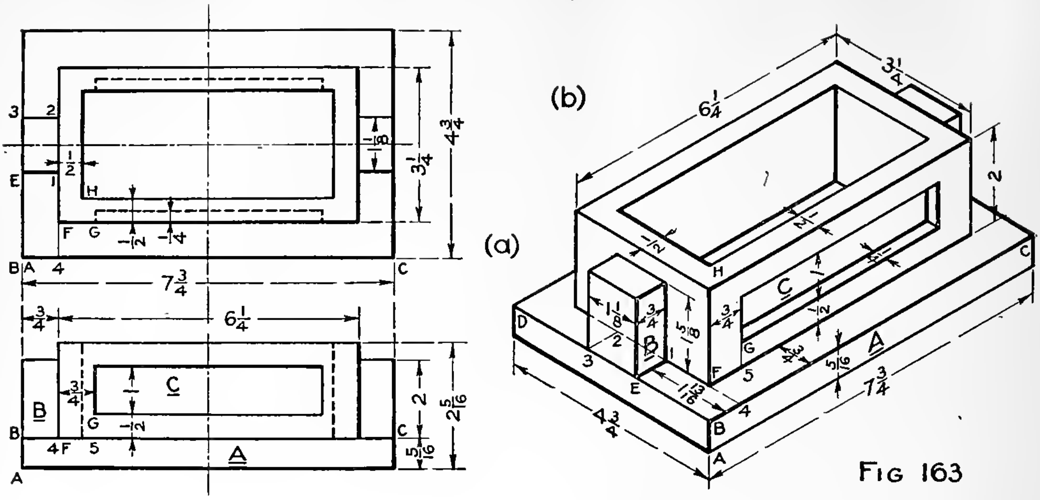


FIG 163

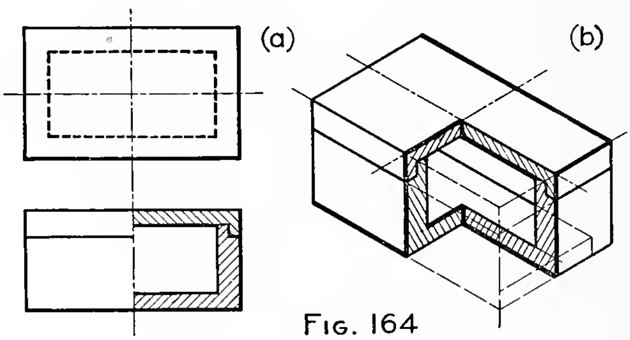


FIG. 164

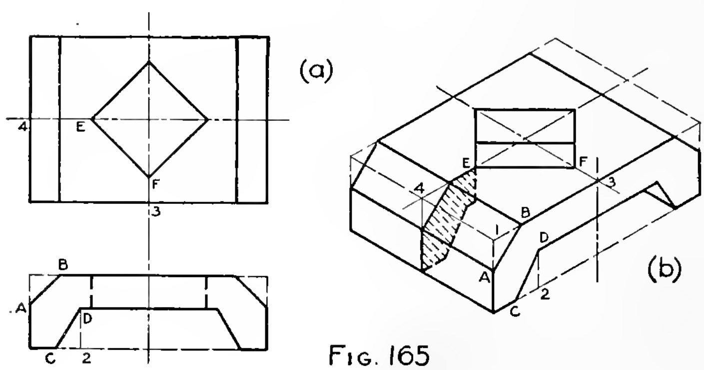


FIG. 165

Details must be built up from the surface or surfaces which they intersect. Thus to draw block (B), locate a corner, as E, and draw the line of intersection E 1 2 3; then proceed practically as with (A).

To draw (C), one of its lower corners, as F, must first be located upon the top face of (A) by means of co-ordinates B-4 and 4-F; that is, by measuring the distance of F from B along lines which will be || to two of the isom. axes. To draw the recess in the front of (C), locate a corner, as G, by co-ordinates F-5 and 5-G, and proceed as before. Corner H is determined in like manner.

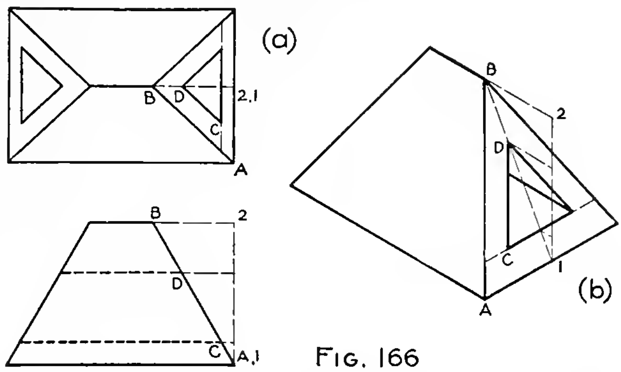


FIG. 166

89. To draw the isometric of an object involving non-isometric figures. The form and position of an integral part of an object are frequently such that some or all of its lines will be non-isom. Such lines are determined in the isom. by co-ordinates || to two or to all three of the axes.

(a) STRAIGHT LINES. In Fig. 165 each of the inclined lines in (a) will be oblique to two of the axes and hence determined by co-ordinates || to those axes, as shown. See also oblique lines in Figs. 171, 172, 194.

In Fig. 166 the line A-B will be oblique to the three axes. The end B, was located in this case by co-ordinates A-1, 1-2, 2-B || to those axes. The end pts. of C-D were determined in like manner.

(b) POLYGONS. In Fig. 167 two sides only of the hexagon ABCDEF will be isom. Each pt. may be referred by co-ordinates to two of the isom. axes, as in (a), or to the sides of a circumscribing rectangle whose sides will be || to those axes.

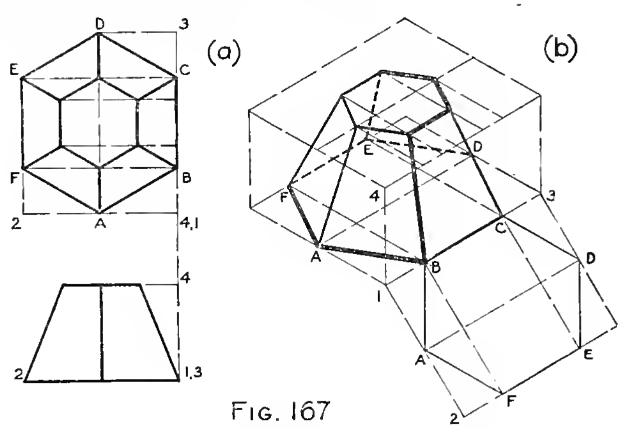


FIG. 167

By placing this rectangle with one of its lines || to or coincident with its isom., one set of dimensions may be projected to the required figure, as shown.

(c) CURVES. The method of determining a curve in an isom. drawing is identical with that of a rectilinear figure save that, in the absence of vertices, pts. must be assumed in the curve and referred to the axes, as illustrated in Figs. 168(a), 169, 170.

The projection of a ⊙ in an isom. plane is an ellipse, in determining which it is convenient to circumscribe a square. Fig. 168(a). As the axes of the ellipse coincide with the diagonals of the isom. square, their end pts. 8, 6, 5, and 7 could be determined by co-ordinates and the curve described by Art. 64(b). See also Art. 64(d), Note 2.

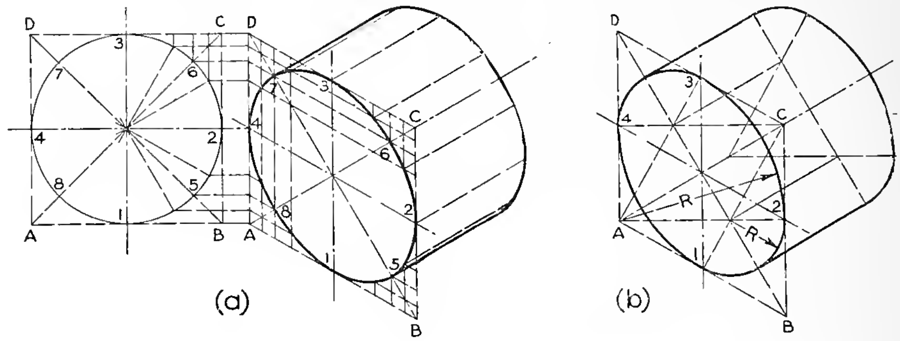


Fig 168

An approximate method of drawing the ellipse by circular arcs, which is usually sufficiently exact, is shown in Fig. 168(b). The centers are the intersections of ⊥s to the sides of the square at the middle pts.

The application of this method to the rounding of corners is shown in Fig. 169. The construction at D determines the radii for all.

To draw a curve not in an isom plane, as A-B (Fig. 170), determining pts. must be located by co-ordinates || to the three axes, as indicated. Screw threads are usually represented conventionally as in Fig. 173.

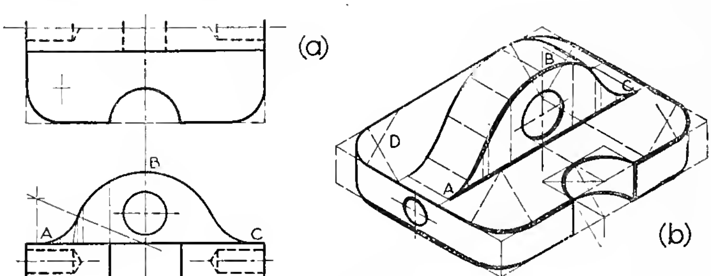
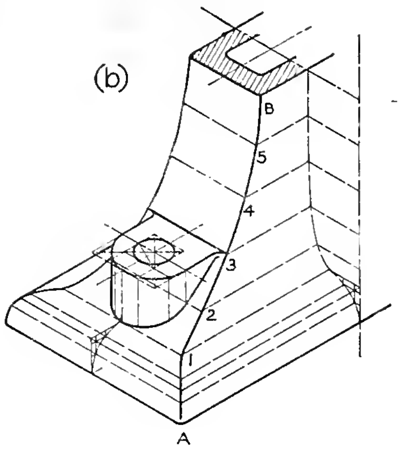


Fig. 169

(d) Solids. The method of drawing an object by inscribing it in an isom. solid is evident from Figs. 167, 171. When it cannot be thus inscribed, pts. must be referred to the axes as indicated in Fig. 166.

In order to preserve the symmetrical appearance of the piece in Fig. 172, it was necessary, either to draw the top view turned through 45°, or to take the hor. measurements for the groove centers on 45° lines instead of on hors. and verts.,



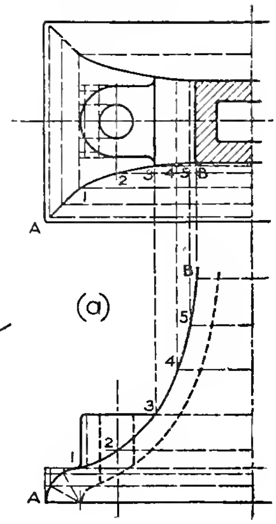
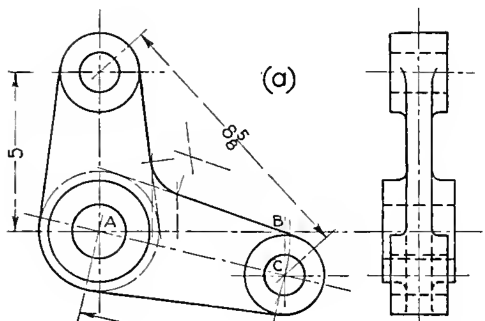


FIG. 170



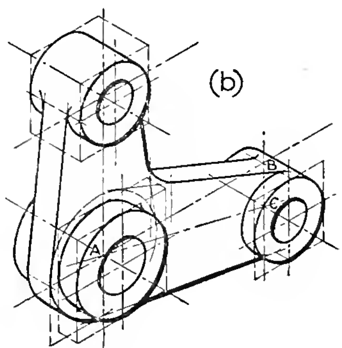
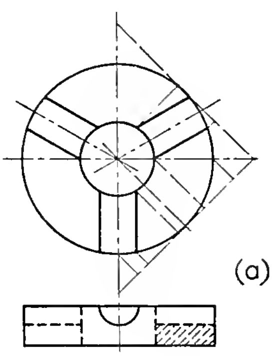


FIG 171



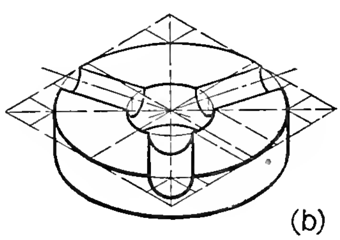


FIG. 172

as shown. Observe that the outer elements of conic surfaces would be tangent to the ellipses and not drawn to ends of the axes. See A and B, Fig. 173.

To determine the outlines of surfaces of double curvature, obtain a series of sections and draw the required curve tangent to the isom. of these, as indicated in Figs. 174, 175, also 149.

90. Oblique Projection. An oblique projection is obtained by means of || projectors oblique to the plane, the object being so placed that two of its axes or principal dimensions are || to the plane. In the case of a rectangular object, as a cube, the view, therefore, gives the true shape and size of its front and rear faces and two dimensions of the object. All lines ⊥ to the plane are projected as || lines whose direction and lengths depend upon the direction of the projectors. They are usually drawn at 30°, 45°, or 60°, up or down to left

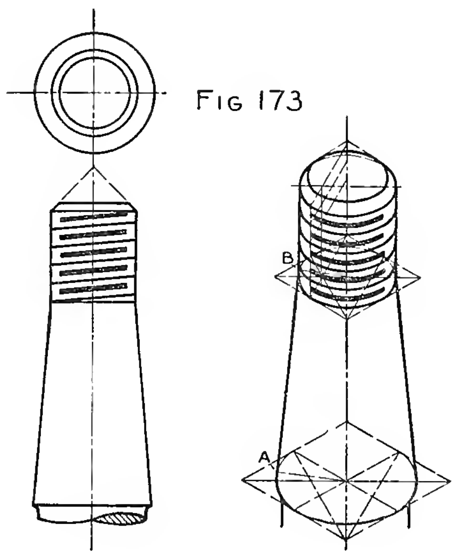


FIG 173

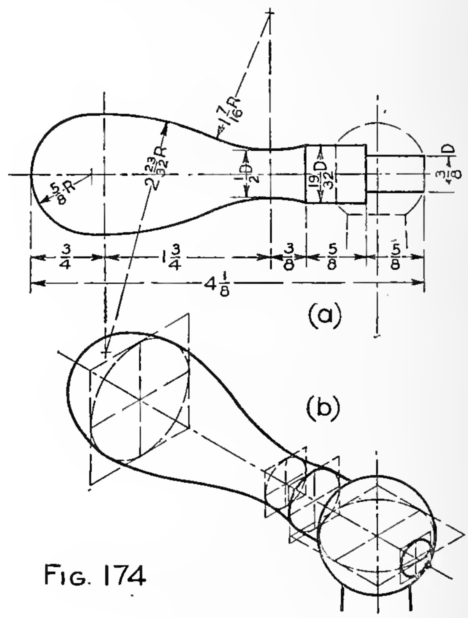


FIG. 174

or right, and made equal to the full scale length of the corresponding lines of the object as in Fig. 176, or foreshortened, usually half, as in Fig. 177. The latter gives a better pictorial effect, but requires the use of two scales, as is evident.

When the receding ⊥s are foreshortened one-half and inclined at 45°, the view is sometimes called a *cabinet projection.*

The axes in oblique proj. are thus a vert. A-B, a hor. A-C, and a line A-D at 30°, 45°, or other ∠. Measurements must be made only upon these axes or lines || to them. Curves, and lines not || to the axes, must be determined by co-ordinates || to the axes, as in isom. drawing.

A circle not || to the plane of proj. will be projected as an ellipse, which may be obtained as in Art. 89(c).

An obvious advantage of oblique proj. over isom. lies in the possibility of representing certain curved and irregular surfaces in their exact shape and size. See applications of principles in Figs. 178, 181.

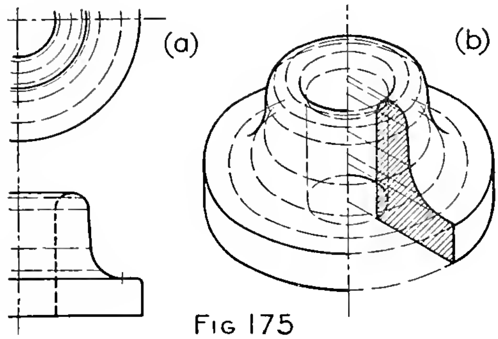


FIG 175

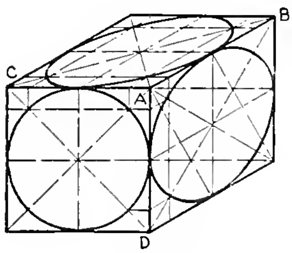


FIG. 176

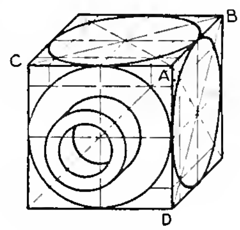


FIG. 177

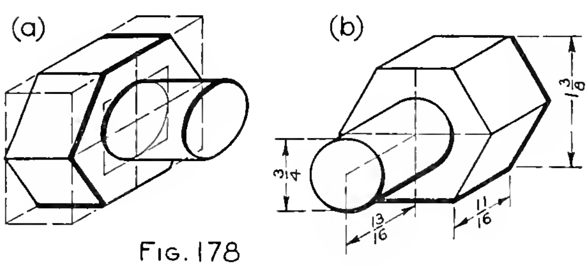


FIG. 178

91. Shade Lines, Shadow Lines, and Line Shading. In finishing, visible edges between light and dark surfaces are frequently shaded, as in Figs. 162(b), 164, 167, 169, 178(a). The indication of these shade lines adds relief to the drawing and increases its pictorial effect.

In isometric drawing the rays of light are assumed || to the plane of proj. and at 30° down to the right. Hence, all rectangular objects and parts, whose lines are || to the axes, have their shade lines in the same relative positions as in the cube. Fig. 162(b).

In oblique proj. the rays are assumed || to the diagonal, C-E, of the cube. Fig. 162(c).

In determining the shade lines, the shadows are disregarded. Elements of curved surfaces are generally not shaded. Edges of cylindric surfaces may be shaded as in Figs. 169, 178(a).

Instead of shade lines, shadow lines may be applied as in Art. 23. (See Figs. 171, 178(b).) Another method is to shade the nearest edges as in Fig. 172. Line shading may be applied as in Art. 24.

CHAPTER X

WORKING DRAWINGS

92. Character and Purpose of the Drawing. A working drawing is a mechanical drawing, containing all information as to form, dimensions, construction, material, finish, etc., necessary to the workman or mechanic in making or building the object which it represents. See Art. 1.

To convey this information readily, the drawing must be accurate; as clear, simple, and direct as possible; and in accordance with shop and drafting practice. It must express the idea completely and definitely and contain nothing that is unnecessary, ambiguous, or misleading. In commercial drafting utility of the drawing and economy of production are the ends sought for in all cases.

The nature of the views of which the drawing is composed is explained in Chap. V.

93. Types of Drawings. In complicated objects composed of different pieces or parts, certain features would inevitably be hidden or not clearly shown; hence, in such cases, two types of drawings are required—namely, *general* or *assembly drawings* and *detail drawings.*

(a) The purpose of a general drawing (Figs. 179, 184, 185, 202) is to illustrate the design of the subject as a whole and to show the relative positions of the different pieces composing it. It may include the complete description of some or of all of the pieces, or give merely such information as may be necessary in assembling them or erecting the object. As a rule, it should be as free from representation of minor detail and hidden parts as possible.

(b) A detail drawing (Figs. 180, 203-206, 210-213) shows each piece by itself and gives all information necessary for making it. In simple objects, full instructions would ordinarily be given in a general drawing, sometimes called a *detailed assembly*. See Figs. 179, 184, 185.

Note.—The table shown in Fig 179 was separately detailed (Fig. 180) for purpose of comparison with the general drawing and to illustrate certain methods of arrangement, dimensioning, etc.

Detail drawings may be shown on the same sheet with the assembly, grouped on separate sheets, or each piece shown on a sheet by itself, depending upon the character of the object, size and number of parts, etc. In general, details of the pieces of one part of an object should be grouped apart from similar groups of other parts (Fig. 205); and so far as possible the arrangement of details of related pieces should be such that reference may readily be made from one to the other. Figs. 180, 205. It is often desirable to show related pieces of a part as assembled. Figs. 181, 182.

In drawings of machinery the special information required by the different workmen, as the pattern maker, the blacksmith, and the machinist, is often

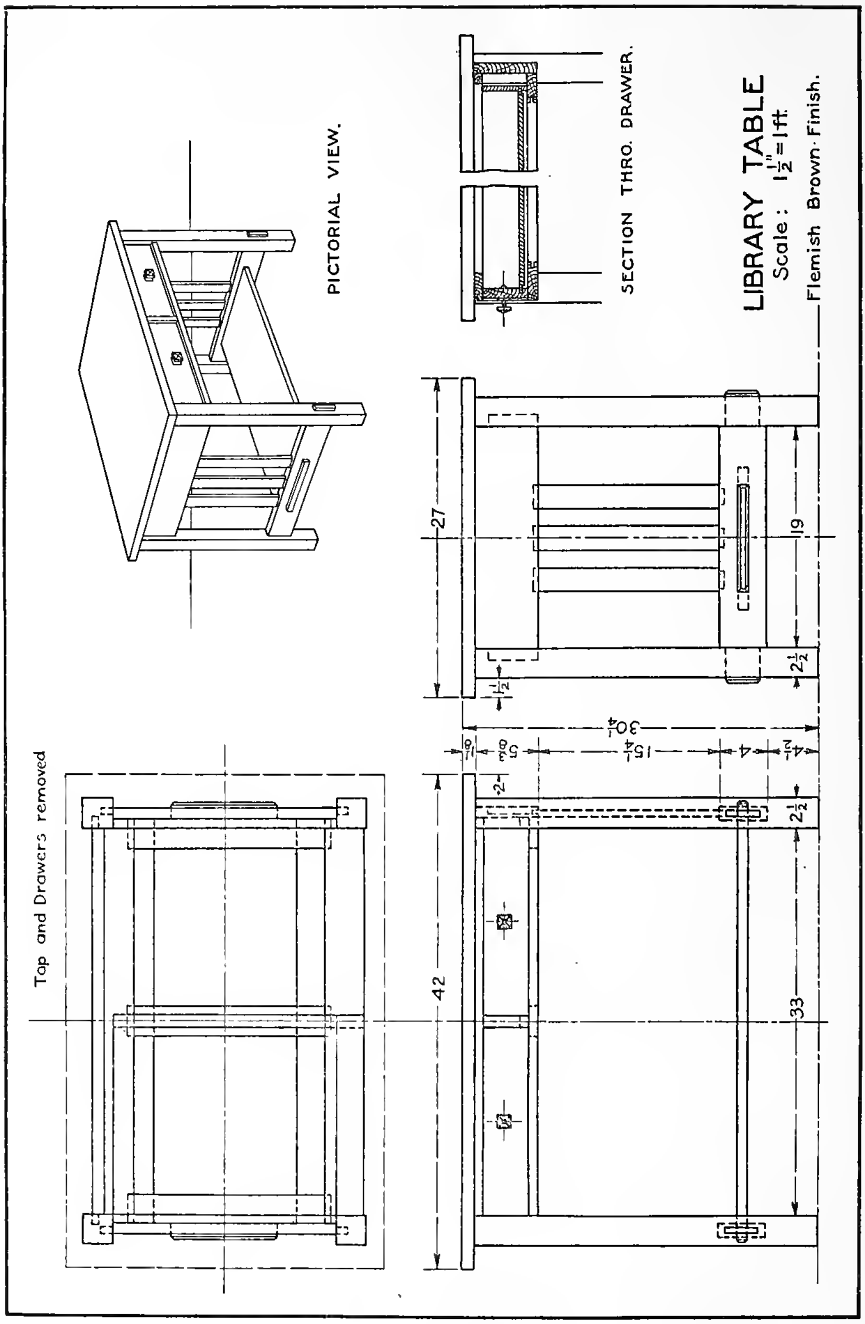

Top and Drawers removed
PICTORIAL VIEW.
SECTION THRO. DRAWER.
LIBRARY TABLE
Scale: 1½" = 1 ft.
Flemish Brown Finish.
42
27
33
19
2½
30¼

FIG. 179

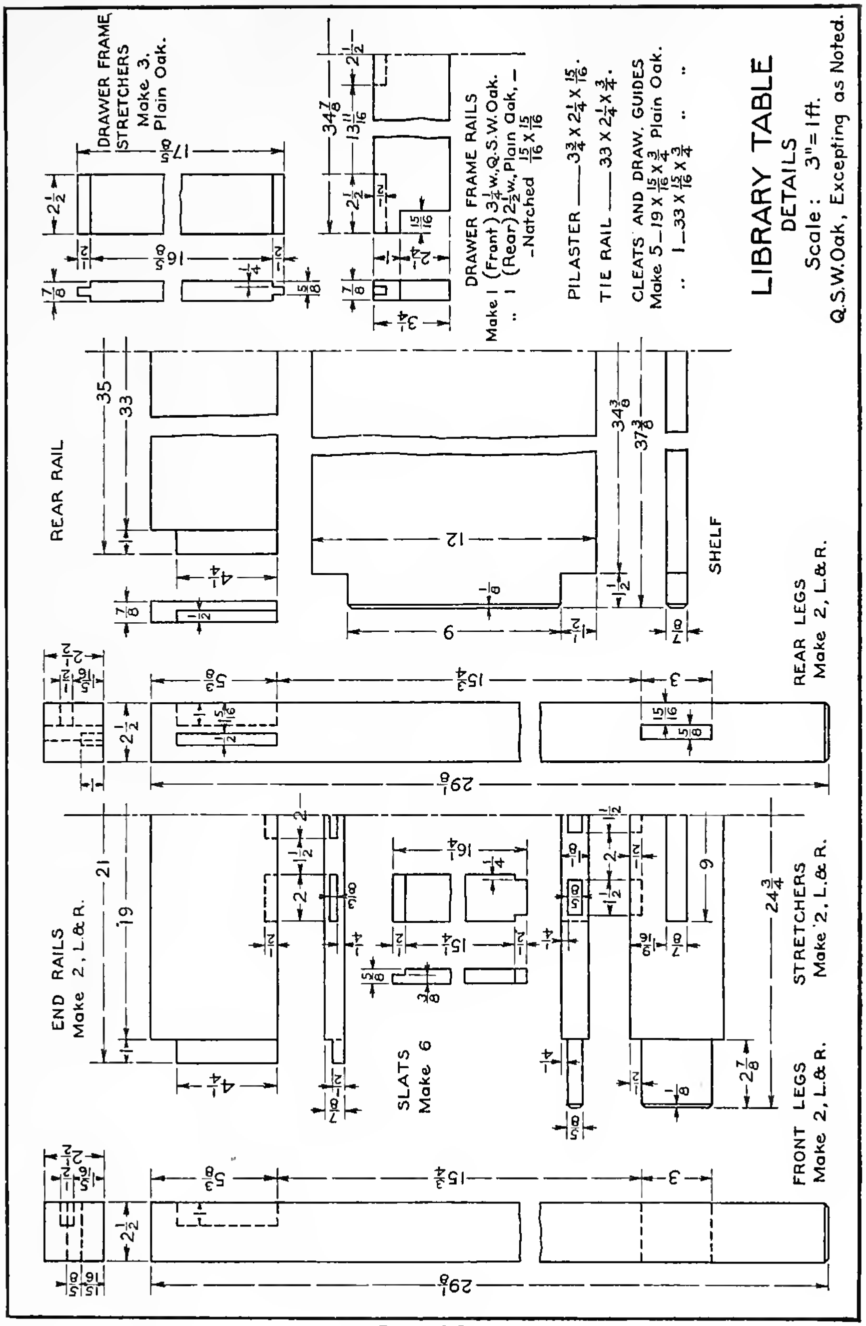

LIBRARY TABLE
DETAILS
Scale: 3" = 1 ft.
Q.S.W.Oak, Excepting as Noted.
DRAWER FRAME STRETCHERS
Make 3.
Plain Oak.
DRAWER FRAME RAILS
Make 1 (Front) 3¼ w., Q.S.W.Oak.
" 1 (Rear) 2½ w., Plain Oak, – Notched 15/16 X 15/16
PILASTER ——— 3¾ X 2¼ X 15/16.
TIE RAIL ——— 33 X 2¼ X ¾.
CLEATS AND DRAW. GUIDES
Make 5 — 19 X 15/16 X ¾ Plain Oak.
" 1 — 33 X 15/16 X ¾ " "
REAR RAIL
SHELF
REAR LEGS
Make 2, L. & R.
END RAILS
Make 2, L. & R.
SLATS
Make 6
STRETCHERS
Make 2, L. & R.
FRONT LEGS
Make 2, L. & R.

Fig. 180

detailed upon separate sheets for each. Likewise work required to be done on certain machines, etc., is often so grouped.

94. Position of Object and Arrangement of Views.

(a) The object should be represented in its natural position, and, when it has a definite front, that part should be shown in the front or principal view. The position of a separate piece, however, should be such as to show best its form, with the fewest lines and views, regardless of its position in the complete object.

(b) In general, a top, side, bottom, or rear view should be related to the front view, as indicated in Fig. 120. When for convenience or necessity they are not thus arranged, it is well to letter them: "Top View," "Side View," etc. See Figs. 181, 192. Other views may be placed where most convenient, the part to which each refers being clearly indicated by its position or by marking. See Figs. 179, 182.

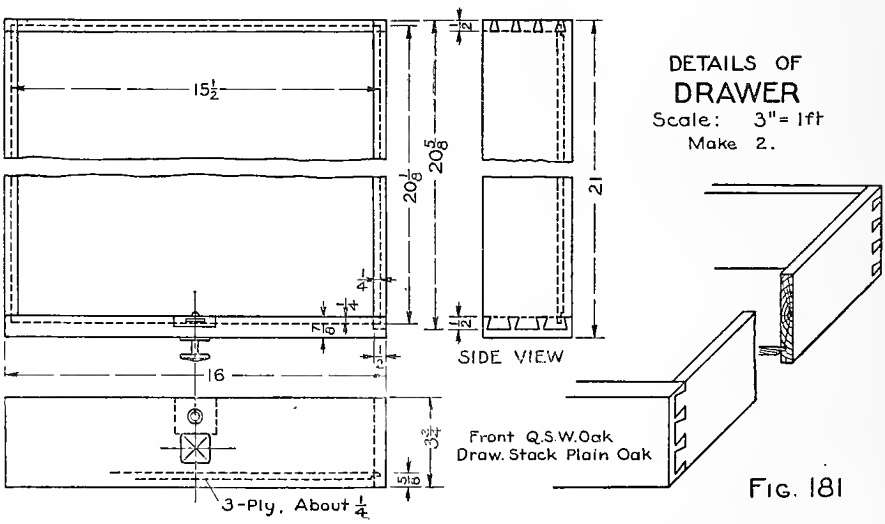


FIG. 181

95. Selection and Number of Views, etc. Those views should be selected for drawing which most clearly and adequately describe the object and require the least time to execute. Views that do not add clearness or convey necessary information should be omitted.

Two or three views are ordinarily required; others, however, are frequently necessary. In simple symmetrical objects one is often sufficient. Fig. 174(a).

In addition to the external views the following are frequently necessary:—

Sectional views—to show interior construction.

Diagrams—to show the direction of motion of moving parts, relations of important centers, etc.

Developments—to show true shapes for surface patterns, templets, etc.

Isometric, or oblique views—to show details of construction, etc., with a pictorial effect.

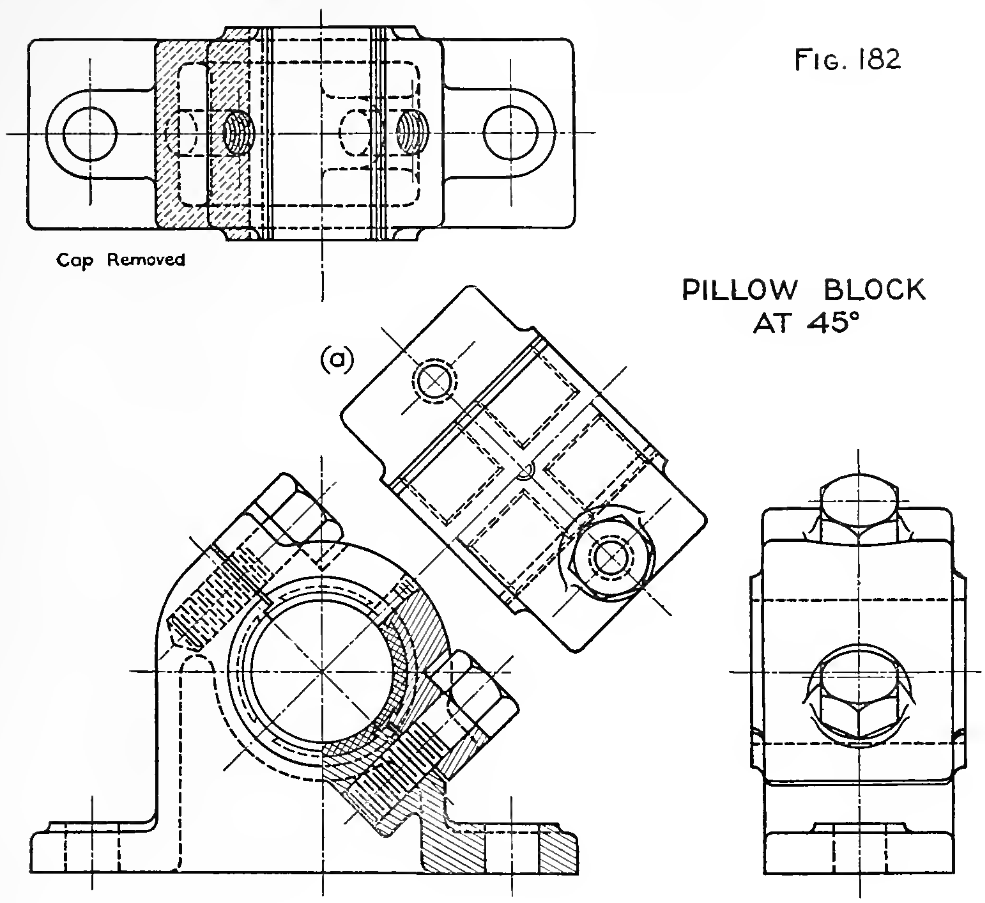


Fig. 182

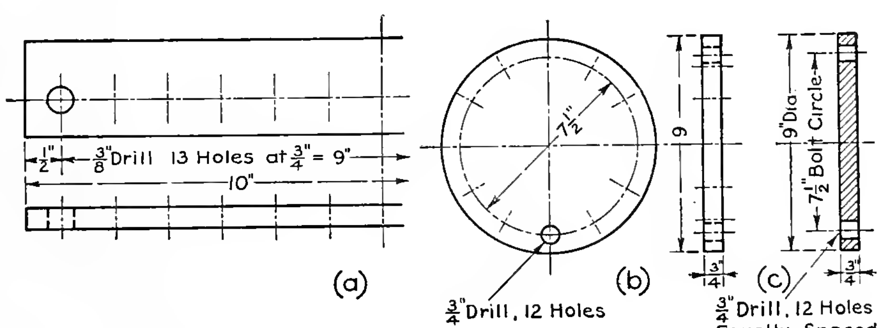


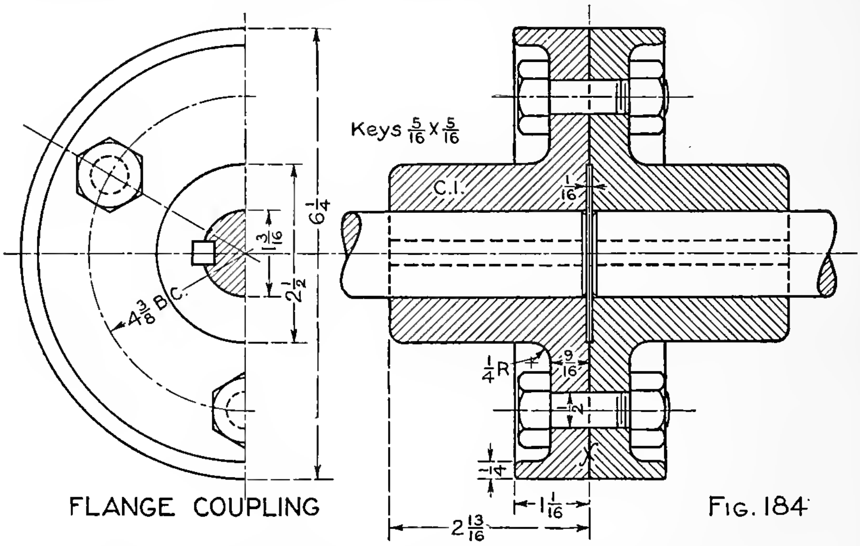
Fig. 183

96. Center Lines. As a rule, symmetrical objects and parts should have their axes and centers indicated by means of center lines. See Art. 66(g). As the object is usually represented with its main axes || to the planes of the views, the main or principal C. Ls. of a drawing are usually vert. and hor. lines passing through the centers of the corresponding views of the main body of the object. These C. Ls. are commonly extended to connect the views.

Secondary C. Ls. are likewise usually ⊥ to each other or to main C. Ls., but are ordinarily not extended. When the centers of a series of symmetrical parts are equidistant from a common center, a circular C. L. is used. The other C. Ls. for these parts are usually radial lines from the center of the circular C. L. Figs. 182-184, 188, 189.

When a C. L. coincides with a line of the object, the latter should be shown. See Figs. 184, 220.

A straight C. L. may be regarded as the edge view of a center plane.



FLANGE COUPLING

Fig. 184

97. Conventional Representations. Instead of true or complete projections it is often desirable, for clearness or economy of labor, to make conventional or approximate representations. Some of the more common methods used are referred to in the following:—

Partial views, as of one-half or other suggestive portion of an object, may often be used in place of *complete views*. Figs. 180, 182(a), 184, 188(a), 192-195, 203-206.

Lines or details clearly shown in one or two views may often be omitted in others, especially those of hidden parts. Figs. 184, 192, 193, 199.

Of a series of similar parts, as holes, bolts, etc., of the same size, it is usually necessary to draw but one or two and to indicate the locations of the others. A brief note often saves the drawing of many lines. Fig. 183.

Screw and pipe threads, bolts and springs, are usually represented conventionally, as in Chapter XI.

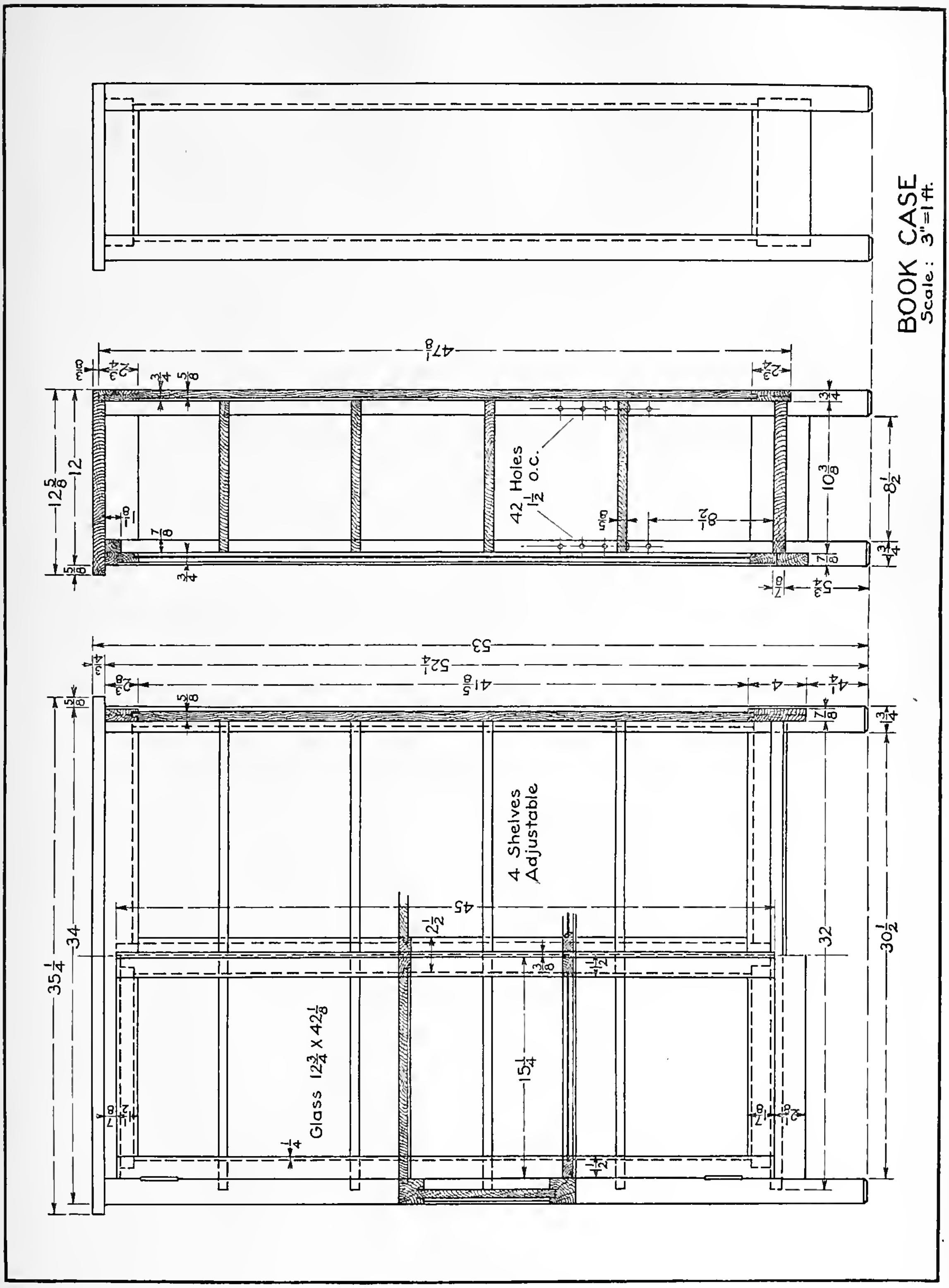

BOOK CASE
Scale: 3"=1 ft.
42 Holes
1½ o.c.
4 Shelves
Adjustable
Glass 12¾ X 42⅛

FIG. 185

Ellipses and other non-circular curves may often be approximated by arcs of ⊙s. Art. 18(b).

Where an edge is rounded so that no definite line of intersection is seen, it is often better to show such line as if existing. See curve a-b, Figs. 188, 208.

In Fig. 184, instead of projecting the upper bolt from the circular view, it is represented at its true distance from the center of the shaft, the same as the lower bolt; thus avoiding confusion of the view and suggesting the symmetry of the piece. For similar reasons the lower arm of the wheel (Fig. 188) would be shown as in (b), the same as the vert. arm., instead of foreshortened as in (c). See also grooves in Fig. 172(a), and slots and ribs in Fig. 189.

Other conventions are described in Arts. 98 and 99.

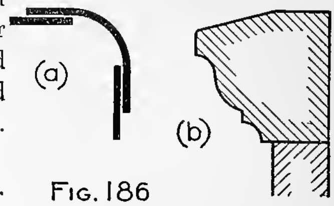


FIG. 186

98. Sectional Views. See Chap. VI.

(a) When a section does not lie in a main center plane, the place where the sec. is taken should be indicated, as in Figs. 179, 188(a), 192, 199. Parts lying beyond the sec. need not be shown unless they add clearness or give additional information. When lines of a removed portion are shown they may be indicated as construction lines. See top view, Figs. 179, 193, 199.

Section lines should have the same direction and spacing throughout all parts of a sec. of any one piece. Fig. 188(b). Different pieces in a sec. are indicated by sec. lining in opposite directions, at different ∠s, or by difference in spacing. Figs. 184, 185, 192. Sec. lines must never cross figures, arrowheads, or notes placed in a sec. See Fig. 184.

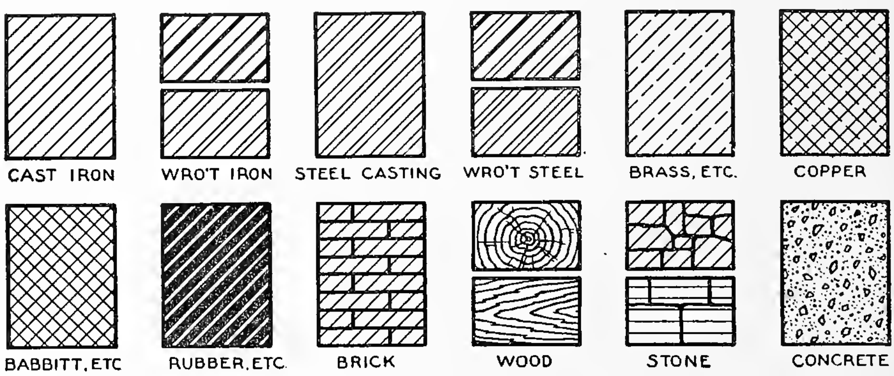


FIG 187

When a sec. is very narrow, it is sometimes filled-in black, and adjacent pieces separated by narrow spaces. Fig. 186(a). Very short sec. lines may be drawn freehand. In large drawings, secs. are often indicated as in Fig. 186(b).

(b) MATERIAL CONVENTIONS. Different kinds of materials may be indicated by different kinds of sec. lining. The conventions shown in Fig. 187 are commonly employed, but there is no fixed standard of practice. Many draftsmen use plain sec. lining for all materials and indicate the kind by lettering. On drawings finished on paper the secs. are sometimes tinted with India ink or colors.

(c) Selection of Sectional Views. A view may show a *complete section*, that is, through the entire object; or a *partial section*. In objects symmetrical about an axis, half only on either side of the C. L. need be sectioned. Figs. 189(b), 192. When a partial sec. is not limited by a C. L. or some line of the object it is usually shown as in Figs. 199, 218(o).

A view need not show all parts in sec. that lie within the sec. plane, unless the drawing is rendered clearer, or additional information given. In general a solid cylindric part as a shaft, rod, bolt, screw, etc., intersected by a plane || to its axis, should be shown in full; likewise a key, rib, tooth, wheel arm, or turned handle.

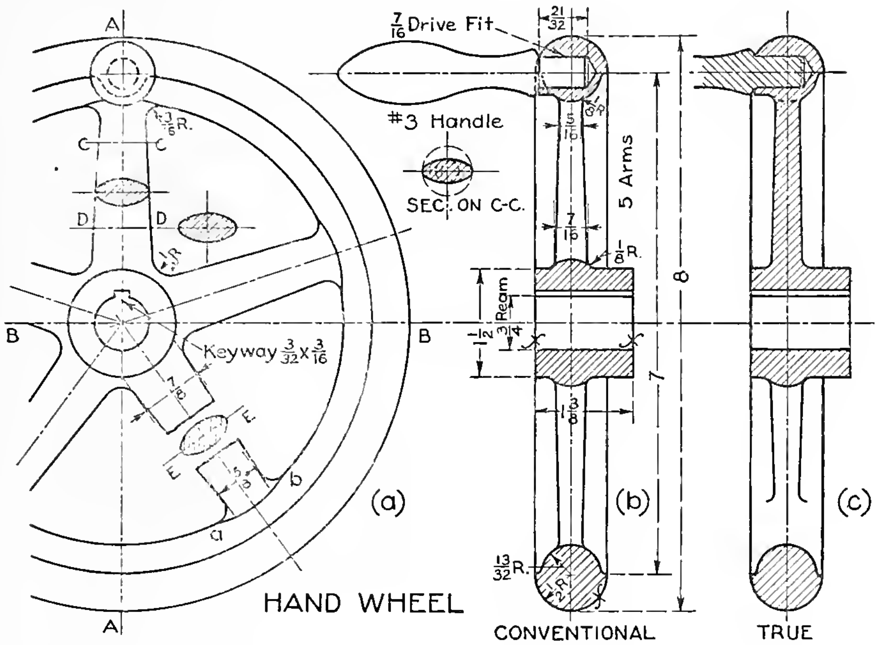


Fig. 188

In Fig. 188(a) the plane A-A passes through the rim, vert. arm, hub, and handle of a wheel. Instead of making a true sec. (c), as projected from the view (a), the draftsman would make the conventional sec. (b), in which the vert. arm and handle are shown in full. He would also represent the lower arm as in the same center plane as the vert. arm. If considered by itself, the true sec. would suggest a solid web between the hub and rim, which would be misleading, while the conventional sec. shows the desired information at a glance.

The conventional sec. of a ribbed piece is shown in Fig. 189(b). The method (c) is also used. Note location of slots in (b) and (c).

It is frequently desirable to show two or more || secs. in the same sectional view. See Fig. 190.

A sec. may sometimes be shown as revolved upon the part sectioned. See sec. on D-D, Fig. 188(a), also 185, 198. In such case the original view is drawn

complete and the sec. in full or dashed lines. It is generally better to "break" the view and show the sec. in the space.

Instead of making a separate sec. view, an *invisible section* may be indicated, as in Figs. 182, 208.

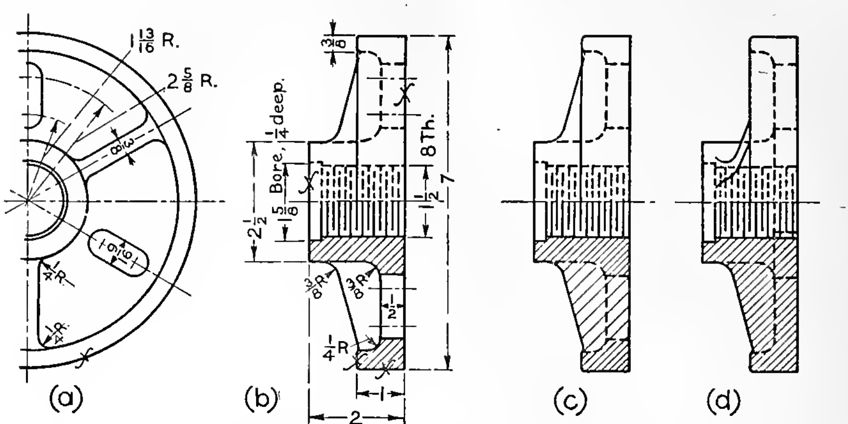


FIG. 189

99. Broken Views. When only a portion of an object is required to be shown and the portion is not limited by C. Ls., the views may be broken, as indicated in Figs. 191, 179, 180, 181, 203, 204. The outline of the break is sometimes omitted. Fig. 188(a).

The broken ends of symmetrical pieces may often be made to suggest the sectional shape.

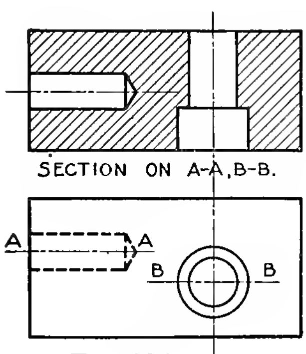


FIG. 190

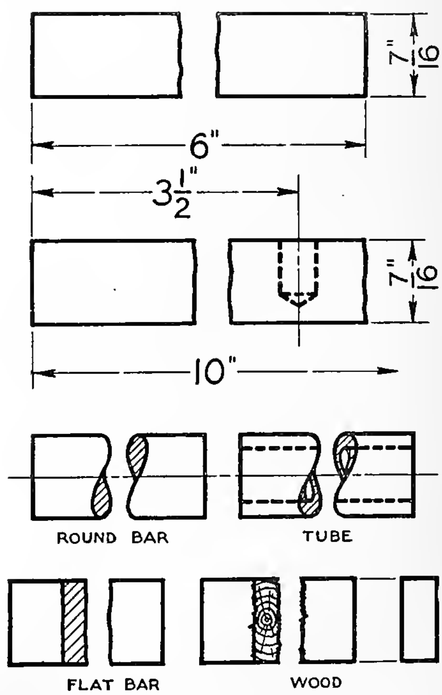


FIG. 191

100. Standard Sizes of Sheets and Scale of Drawings.

(a) For convenience in handling, filing, etc., the drawings are usually made upon sheets cut to standard sizes, which are peculiar to each shop or office and dependent largely upon the uses for which the drawings are intended. For sizes in common use, see Art. 4.

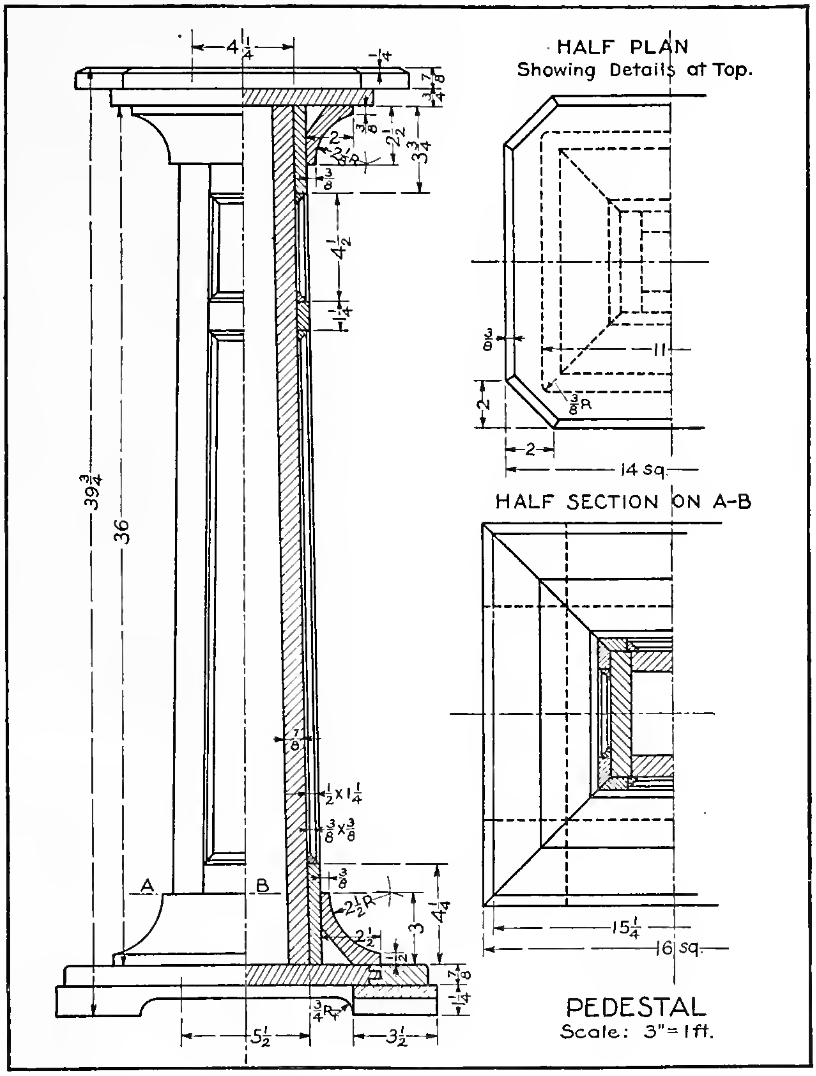


FIG. 192

(b) All drawings are made to a definite scale. Art. 11. The scale chosen must be such that all parts and dimensions will be shown clearly. Details should be to full size, if practicable; small details to an enlarged scale, if necessary. It is desirable, however, that all drawings on a sheet be to the same scale.

Scales commonly used are full size, and $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{12}$, $\frac{1}{24}$, and $\frac{1}{48}$ size. These are usually stated on the drawing thus: Scale: Full Size. Scale: Half Size. Scale: 3″=1 ft. Scale: $1\frac{1}{2}$″=1 ft., etc.

(c) To determine the scale necessary to be used for a given size of sheet, find the ratio of the available space to the full size dimensions, making due allowance for spaces between the views and from margins. Thus, supposing the drawing space horizontally to be $13\frac{1}{2}$″ minus 2″ for spaces, and the hor. dimensions 20″ plus $3\frac{1}{2}$″, the ratio would be $11\frac{1}{2}$ to $23\frac{1}{2}$ and the nearest convenient

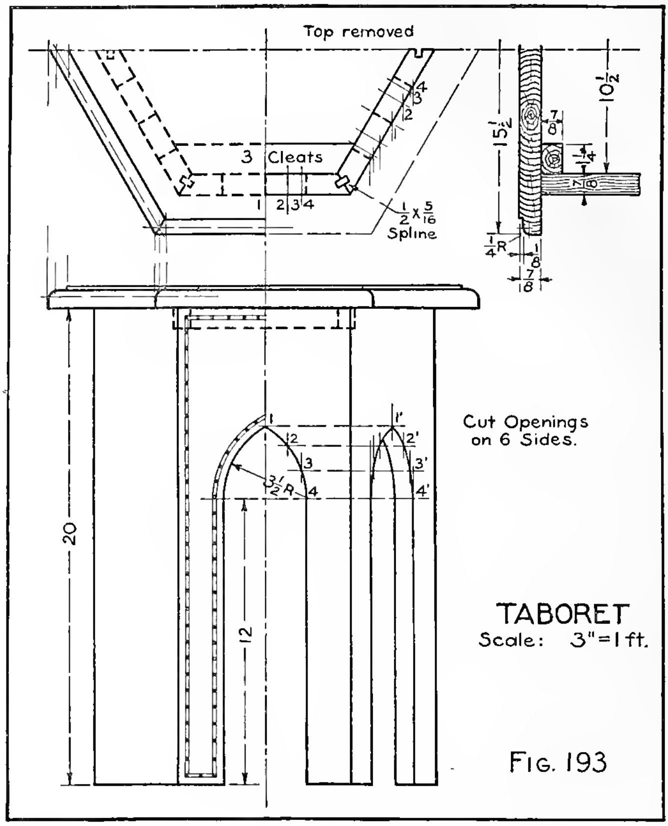


FIG. 193

scale, considering the hor. dimensions and spaces only, would, therefore, be half size or 6″=1 ft. To aid in such calculations, the layout sketch would be used. Art. 105(a).

101. Dimensioning. Although the drawing is made to a definite stated scale, generally, the accuracy of the views themselves is not depended upon to indicate the size of the object even when drawn full size; all dimensions required by the workman must be shown upon the drawing in figures, or otherwise definitely specified.

In order to give the essential dimensions and to omit those that would be unnecessary, misleading, or impractical, the draftsman must consider the needs and convenience of the workman, and the successive steps and processes involved

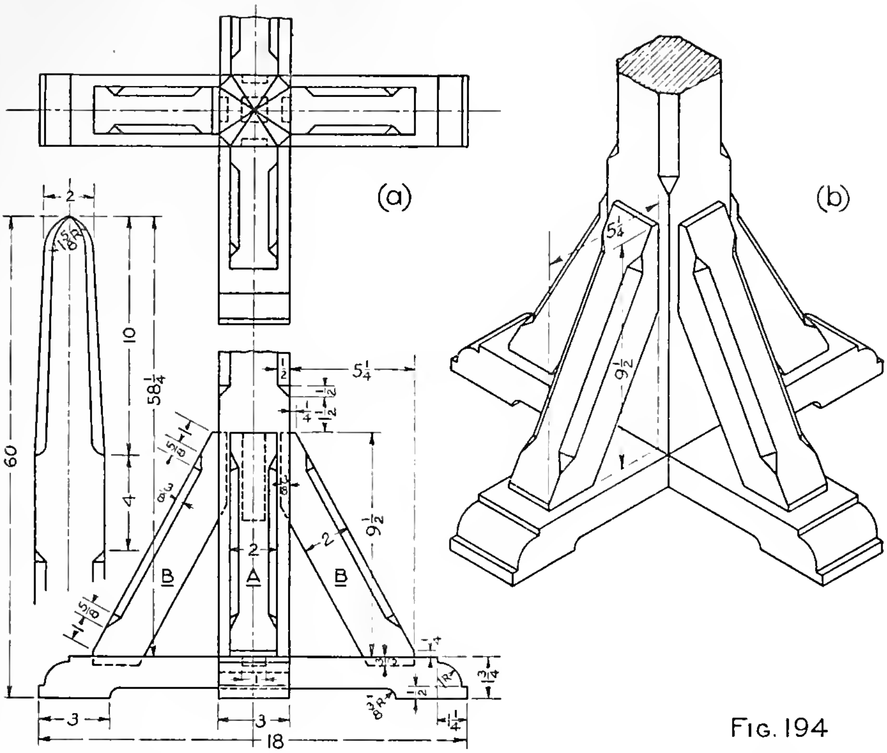


FIG. 194

in the construction of each part. In addition to a knowledge of shop requirements, he must exercise good judgment in deciding where to place the dimensions, so that they can be easily found and applied. This article describes the methods of dimensioning for commonly occurring cases.

(a) FORMS OF DIMENSIONS. To allow for the use of a two-foot rule in working, ordinary dimensions less than two feet are usually given in inches and halves, 4th, 8ths, etc.; thus, $17\frac{3}{64}''$. Others are given in feet and inches; thus, 2'-0", 2'-6", 2'-0½"; or thus, 2 ft. 0", 2 ft. 6", 2 ft. 0½". Some offices use inches

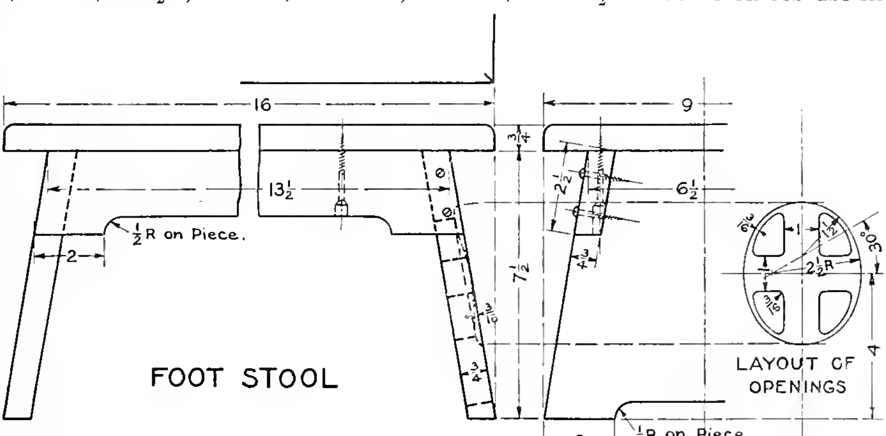


FIG. 195

up to 36, others up to 72, and in some classes of work all dimensions are given in inches. When the greatest possible exactness is required, dimensions must be given in decimal form; thus, 0″.94, 2″.442. When all dimensions are understood to be in inches, the sign (″) may be omitted. Limits of allowable variation in size are often indicated thus, $\frac{1.500}{1.498}$, which means that the measurement must not be greater than 1.500 nor less than 1.498.

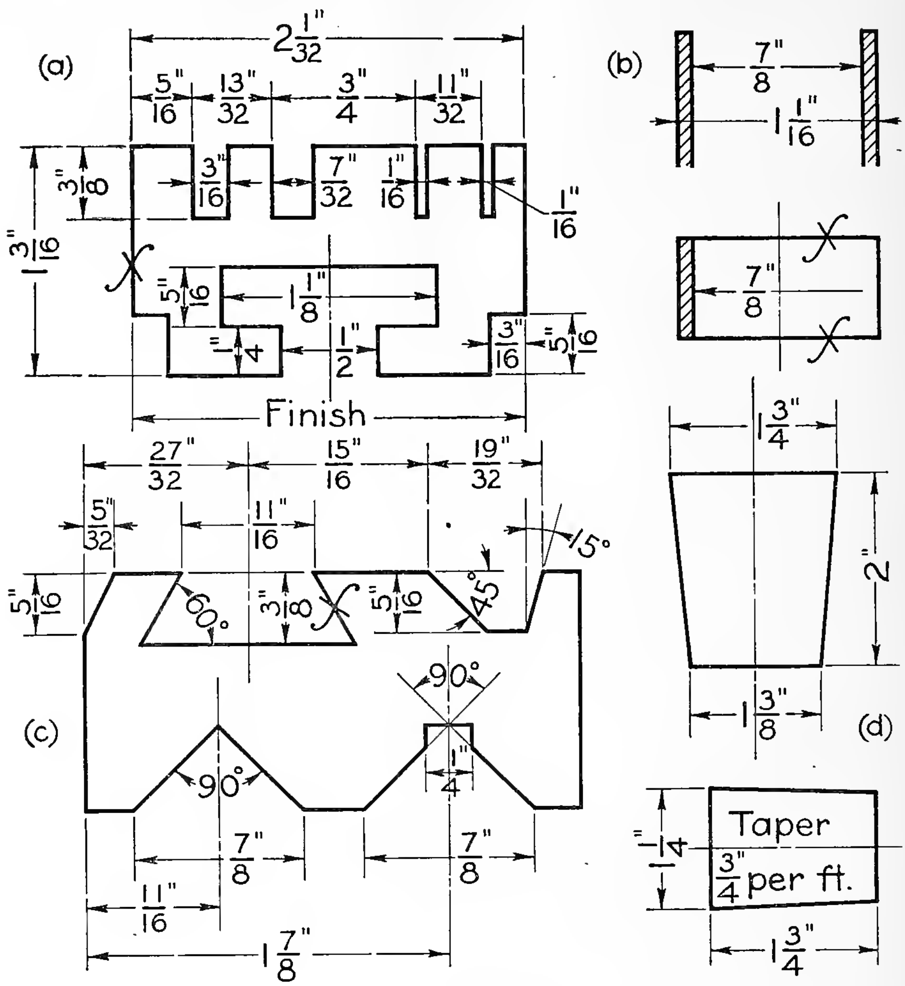


FIG. 196

(b) DIMENSION LINES, FIGURES, AND ARROWHEADS. The *figures* are placed upon *dimension lines*. These lines, with the exception of those for radial dimensions and unlimited distances, have *arrowheads* at both ends. For forms and sizes of figures and arrowheads, see Figs. 73, 74. Arrowheads must touch the lines between which the dimension is given, and the figure must state the full size of the corresponding measurement of the object regardless of the scale of the drawing. Acceptable methods of placing figures and arrowheads are shown in Figs. 196, 197.

Figures should be so placed that they can easily be read from lower and right sides of the drawing. Avoid placing a figure where it will interfere with others, or with other lines.

It is not permissible to place the figures for more than one dimension between the same arrowheads, nor upon other than dimension lines.

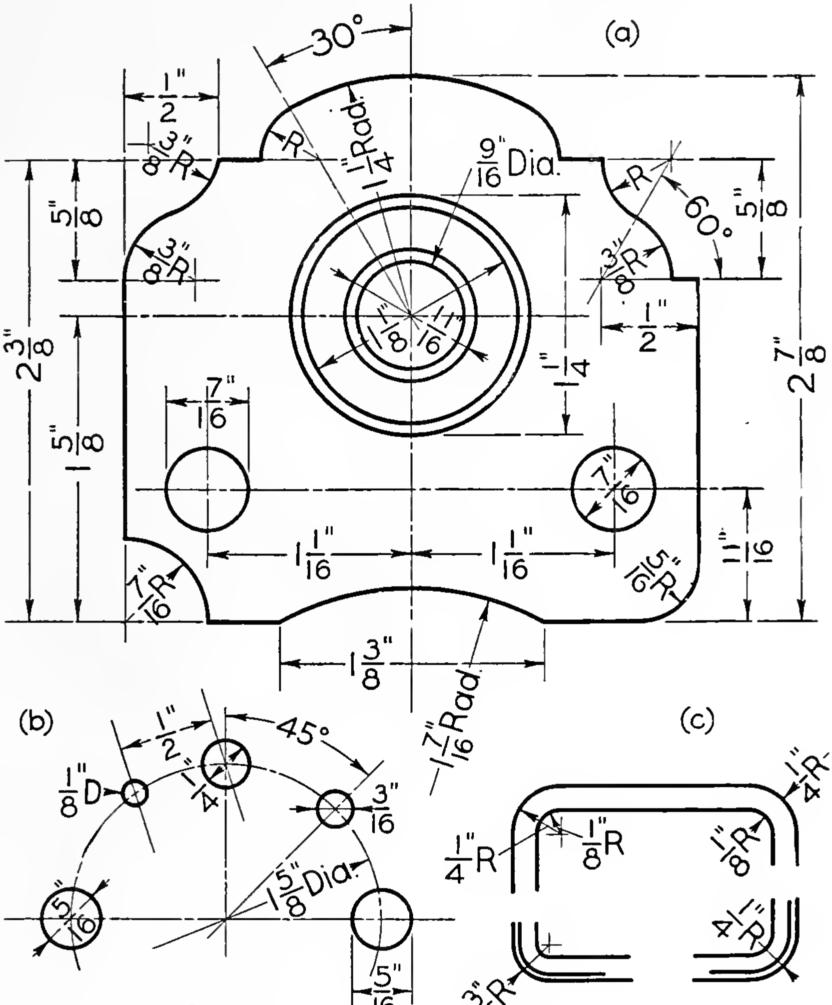


Fig. 197

(c) Locations of Dimensions. Dimension lines for linear measurements must always be ⊥ to the parallels between which the dimensions are given, and ordinarily not nearer than $\frac{1}{4}''$ to object lines and other dimension lines, C. Ls., etc. They should not cross each other or any line of the views, nor be drawn as continuations of other lines, if avoidable. In general, place dimensions outside of views, unless greater clearness and ease in reading will result by placing

them otherwise. Dimensions may be extended beyond parts dimensioned by means of *extension lines*. *Pointers* may also be used. Figs. 196(a), 201.

Never dimension a distance in a view in which it is foreshortened. Dimension a detail preferably in a view in which it is visible. So far as practicable give related dimensions, as of the length, width, and location of a hole, in the same view. Dimensions clearly given in one view should not be repeated in another upon the same sheet. When parts are obviously alike, dimension one or two only.

Distances should be given from lines which represent finished or trued surfaces, and from C. Ls. Do not give distances from C. Ls. when not necessary. Locate symmetrical parts, in general, by giving distances to their C. Ls. Figs. 196, 197, 183, 184. In a series of such parts, give distances between centers. As a rule, give dimensions of successive distances in the same direction from the same surface or C. L. The final dimension of a series is sometimes omitted to indicate this surface or line more definitely. Give total or *overall dimensions* as well as all *detail* or *sub-dimensions*, so that the workman will not be obliged to calculate.

Place || dimension lines in the order of their length, the longest farthest from the part dimensioned, to avoid crossing the dimension lines and causing confusion. Figs. 180, 196, 198.

(d) Angles and Tapers. Lines appearing to be hor., vert., or $\perp$ to each other are assumed to be so unless otherwise dimensioned. An $\angle$ may be dimensioned by co-ordinate dimension lines, or by an arc described from its vertex as center. Fig. 196(c). See also 171(a). Common methods of dimensioning tapers are shown in Fig. 196(d). Short tapers are sometimes dimensioned in degrees. Standard tapers are specified by number and kind; as, "No. 2 Morse Taper," etc.

(e) Circles and Arcs. In general, give the diam. dimension of a $\odot$ and place the figure on an oblique diam., or extend the dimension to the most convenient location. Fig. 197(a). Small $\odot$s may be dimensioned as in Fig. (b). Give the rad. of an arc with an arrowhead at the curve end only. When the space is too small for the figure, dimension as in (c). Radii $\frac{1}{8}''$ or less, of fillets and finish arcs, ordinarily need not be given. When the rad. is known or unimportant, indicate by Rad. or R. When holes or bolts are arranged in a $\odot$, give diam. or rad. of the circular C. L. When equal spacing is not evident, specify by note "Equally Spaced." If unequal, dimension as indicated in Fig. 197(b).

(f) Irregular or Non-Circular Curves. These may usually be dimensioned by giving the lengths and positions of offsets $\perp$ to appropriate base lines. Fig. 198, also 174(a). In most cases, however, it is more practical to omit such dimensions*, and to provide the workman with one or more exact patterns or templets of thin material against which he can lay out the curves directly on the piece.

*Fig. 198 is thus dimensioned merely to illustrate the method.

(g) Round, Square, Hexagonal, and Octagonal Pieces. When the circular, square, etc., shape is not shown in any view, nor specified by note or title, indicate by Dia. or D., Sq., Hex., or Oct., after the diameter dimension. Figs. 174(a), 199.

(h) Standard Measurements.

Screws, pipes, bolts, and springs: give dimensions as in Chap. XI.

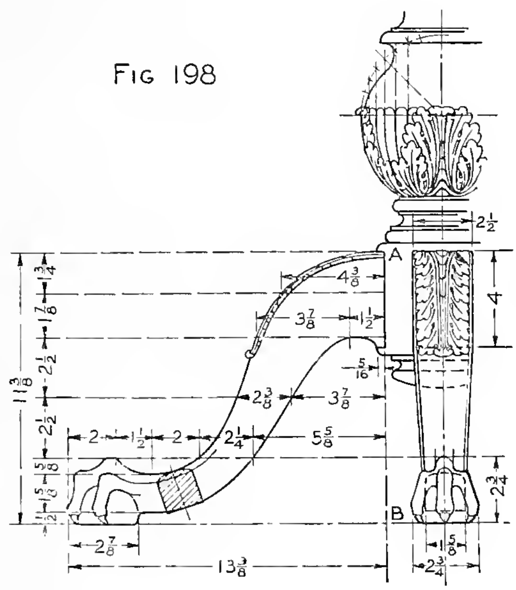
Tubing: give outside diam. and thickness by gage, or in thousandths of an inch.

Wire: give diam. by gage, or in thousandths of an inch.

Sheet Metal: give thickness by gage, or in thousandths of an inch.

(i) Assembly Drawings. The dimensions required depend largely upon the kind of object and the purpose of the drawing. In machine assemblies usually only the important overall dimensions and locations of principal C. Ls. are necessary.

Fig 198



102. Lettering.

(a) Explanatory Notes, etc. Specifications and directions concerning the kind of material to be used, the name and number wanted of each piece, kind of finish to be given, kind of fit required, and any other necessary information not shown by the drawing or stated in a title or bill of material, must be expressed in brief, concise notes lettered upon the sheet. See Art. 25. Notes should preferably be located outside of the views and to read horizontally, or vertically from the bottom. The part noted may be indicated by a pointer. Fig. 188.

Finished Surfaces. When a surface of a casting or forging is to be machined or finished by filing, turning, milling, grinding, etc., an allowance must be made on the piece for this finish. Ordinary finish is generally indicated by a letter f, placed on the surface in all views which show the surface as a line. Fig. 196, also

189 (a), (b). The f's should be placed to read horizontally as shown. When the piece is to be finished all over the f's are omitted, and the note "Finish all over" or "F. A. O." placed near the principal view. The limits of a finished portion

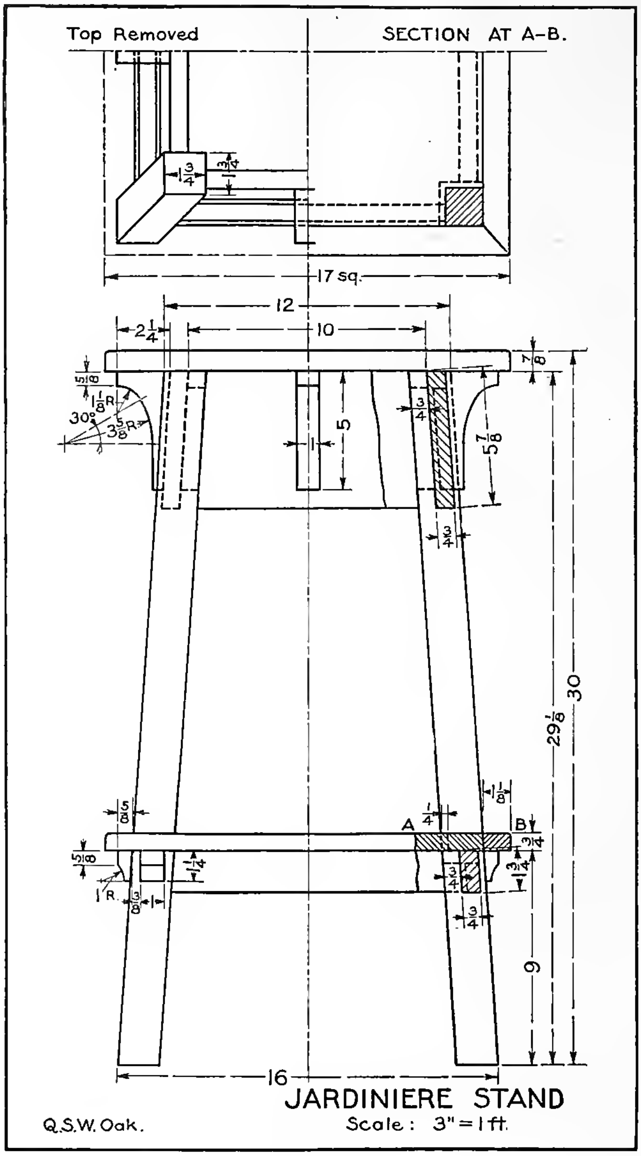


FIG. 199

may be indicated as in Fig. 196(a), or by a note. It is often necessary to specify the kind of finish; as "Polished," "Ground," "Milled," "Reamed," etc. In this case the f's are also usually omitted.

When a portion of an unfinished surface is to be machined to form a bearing

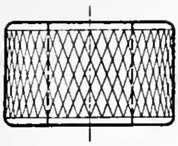


Fig. 200

for a bolt-head, nut, stud-shoulder, etc., it may be specified thus, "Spot Face," or "Counterbore to Surface," according as an allowance is, or is not, to be provided for this finish.

Knurled surfaces are indicated by the word "Knurl," or as in Fig. 200. The varying spaces and ∠s of the lines are estimated by eye.

Circular Holes. "Cored," "Drilled," "Countersunk," etc., holes should be specified in one view, or the other, as in Fig. 201; "Tapped" holes as in Fig. 218.

Kind of Fit. When one metal piece is to be fitted into another, the fit is specified as "Running, "Drive," "Force," or "Shrink" Fit; or by indicating the limits of variation in the sizes of the parts. See Art. 101(a).

Treatment of Metal. Special treatment is specified, as "Tempered," "Hardened," "Case Hardened," "Blued," etc.

Standard Parts. Parts such as screws, bolts, keys, etc., which conform in design and dimension to recognized commercial standards are usually omitted from the detail drawings and specified by note, or listed in a bill of material. Art. (d).

(b) Identifying Marks. It is customary to give each piece of a machine a distinguishing number or letter under which it is listed and referred to. A corresponding mark is placed on the drawing of the piece and is often accompanied by its name. Figs. 202-206, 210-213.

(c) Titles. For convenience in filing, etc., the title of the drawing is generally placed in the lower right corner. Figs. 179-180, 202-206. The title should designate:—

1. The name of the object, part, or particular detail shown, or all three.
2. The scale, if uniform.
3. The date of completion of the drawing.
4. The draftsman's signature.

If a single detail only is shown, the number required and material are generally stated. Some or all of the following information is also generally included: The type of drawing,—as assembly, detail,

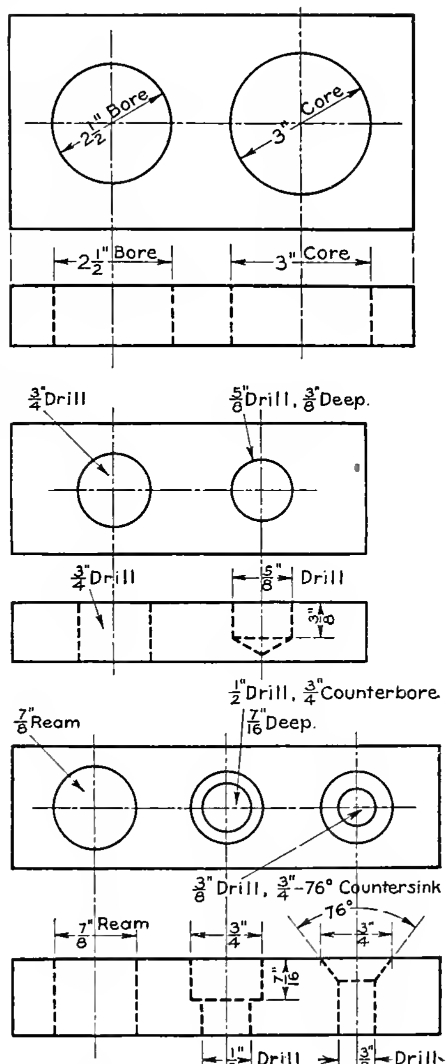


Fig. 201

shop, etc.; the signatures of the tracer and persons by whom the drawing is checked and approved; the firm for whom the drawing is made; references to other drawings, etc.

Sub-titles. On a sheet of details each piece may have a title, consisting of its name and identifying mark; the scale, if not stated in the main title; number required if more than one; material; pattern number, if a casting; and finish, if to be all over. If a bill of material is given, the identifying mark and the scale only are necessary.

Planning a Title. First write the title upon a separate paper. Having decided upon the statements to be included, and the size and style of lettering, proceed to draw the vert. C. L. of the title space and the guide lines for the heights. Next, upon another paper and adjacent to its upper edge, compose and sketch the first line of lettering to the size to be used upon the drawing. Then, placing this sketch against the proper guide line, with the middle point of the line of letters at the C. L., point off the widths of the letters and draw each carefully. Proceed in like manner with other lines of lettering.

(d) FILING INDEX AND BILL OF MATERIAL. A *filing index* giving the number or other designating mark of the machine and the sheet number is usually placed in the lower right corner or included in the main title. It is often shown in an upper corner also. Figs. 202-206, 210-213.

In a set of drawings, the assembly may be indexed as sheet 1, and may include a list of the other drawings with their numbers. The sheet number of each detail may be given near its identifying mark; thus, (3-5): the 3 indicating the mark, and the 5 the sheet no. containing the detail.

A sheet of details is usually accompanied by a *bill of material* placed above or at the left of the main title, accounting for each piece and giving its mark, name, material, no. wanted, and other necessary description and information. For material to be cut to size, the rough stock dimensions should be specified.

When the number of parts is large or more than one sheet of details is necessary, a separate bill grouping the forgings, castings, etc., and giving the sheet no. of each part, may be made. Fig. 213.

(e) ABBREVIATIONS. The following are some of those in common use:—

R. H.	Right-hand	S.	Steel	O. H. S.	Open Hearth Steel
L. H.	Left-hand	M. S.	Machine Steel	C. H. S.	Case Hardened Steel
C. I.	Cast Iron	T. S.	Tool Steel	S. C.	Steel Casting
W. I.	Wrought Iron	C. R. S.	Cold Rolled Steel	Bz.	Bronze

103. Shadow Lining and Line Shading. Arts. 23, 24. Shadow lines and line shading are used when the advantage gained in clearness and effect is sufficient to warrant the expenditure of the time necessary to apply them, otherwise they are omitted. They are of special value on drawings of complicated objects shown by few views or whose corresponding views are upon different sheets, as in some assembly drawings. They are rarely used on ordinary detail or shop drawings.

104. Sketching. To the designer, draftsman, or mechanic, skill in making freehand sketches for the rapid expression of ideas of exact form and structure,

SL-10-1

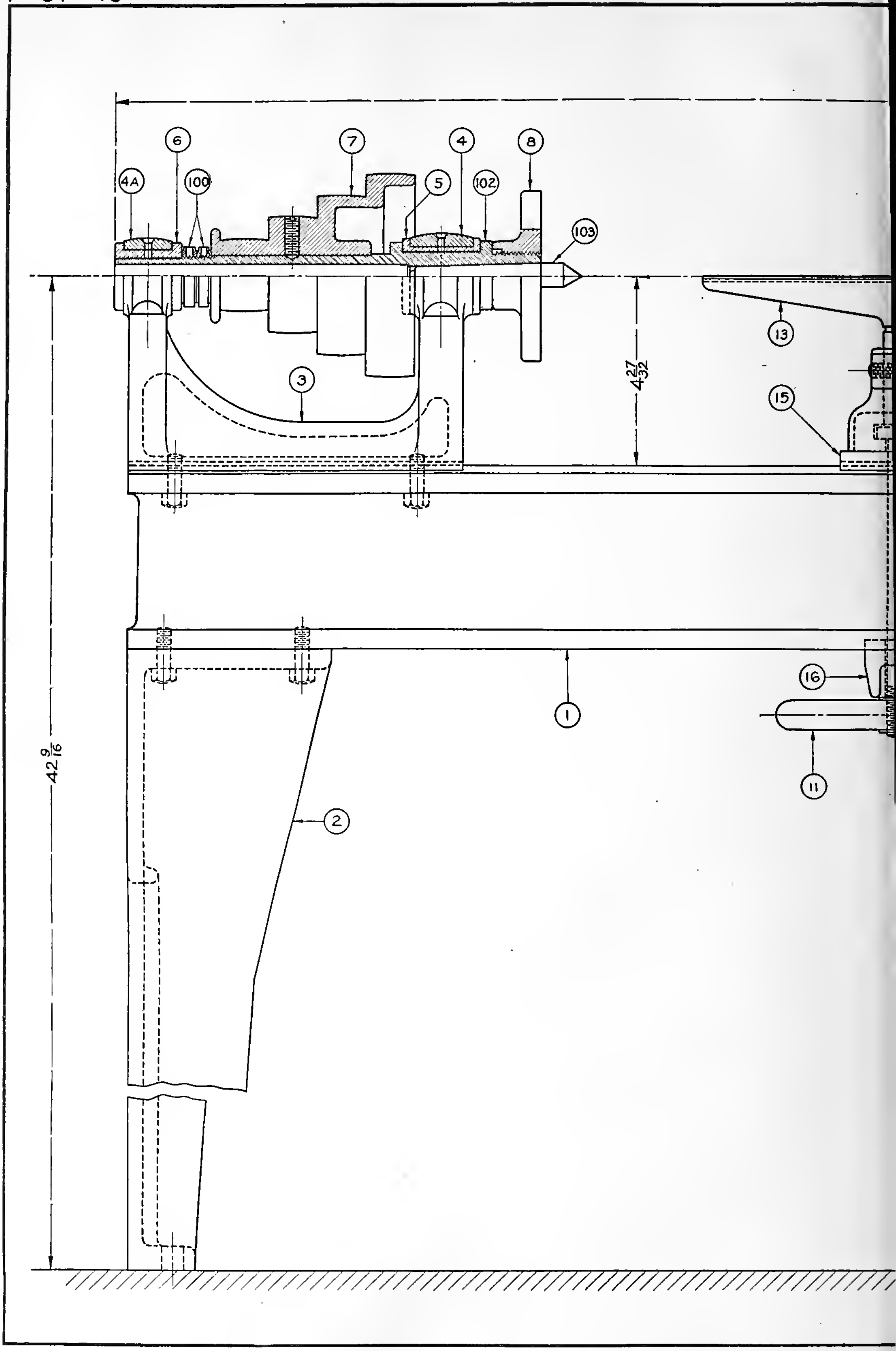
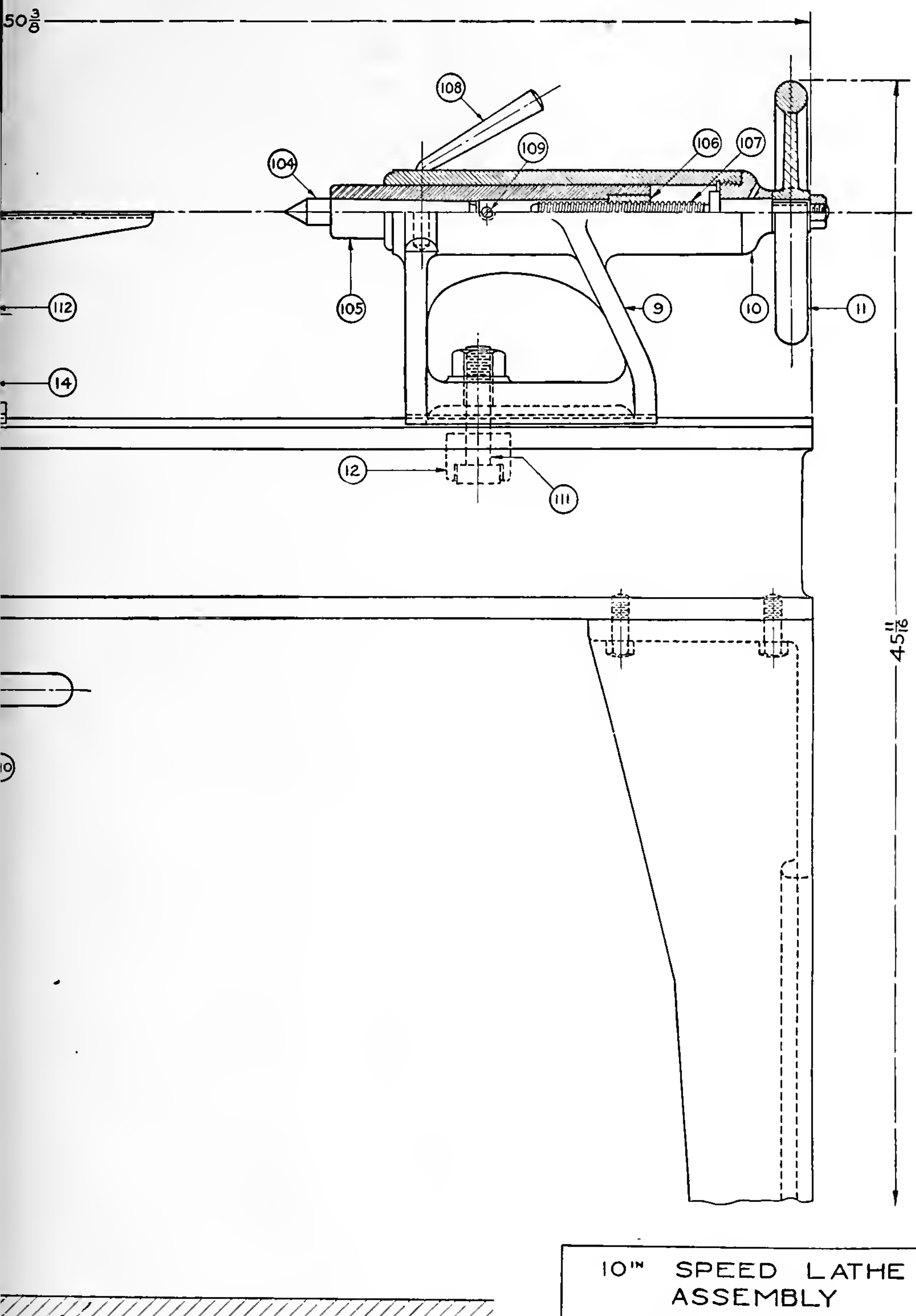


FIG 202



10ᴵᴺ SPEED LATHE
ASSEMBLY
DAY MF'G. CO. BOSTON

Scale 6" = 1 Ft Date 1-29-16

Dr E.M.S. Tr R.O.D. Ch. M.E. App. L.F.

SL-10-1

and as an aid in the solution of constructive problems, is of great importance. To the student, careful sketching is fully as valuable, as a means of acquiring ability to make and to read working drawings, as instrumental drawing.

(a) In making working sketches from objects the following order should be observed:—

1. Separate the parts, if necessary, and sketch the views of each in detail. Begin with the main C. Ls. and principal surfaces, blocking in first the larger details of the piece and proceeding in like manner down to the minor details. See Fig. 209 (a), (b), (c).

Distances and directions are generally determined by eye. Co-ordinate paper, ruled in $\frac{1}{4}''$ or $\frac{1}{8}''$ squares, is often used and affords a more ready and accurate means of obtaining the desired proportions, etc. For use of pencil see Art. 9(b).

The number and character of the views should be such as to express all required facts clearly. Leave nothing to memory. Make the sketches large enough to prevent crowding the notes and figures. The sketches should be intelligible to any one familiar with working drawings, and should enable the scale drawings to be readily made from them without having to resort to the object. Isometric or oblique views may often be used to advantage.

2. Indicate the finished surfaces and put on the necessary extension lines, dimension lines, and arrowheads.

3. Obtain the dimensions by careful measurement of the object and put on the explanatory notes.

Each piece should be dimensioned independently of the others.

(b) Measuring Objects. In taking measurements, a foot, or a two-foot rule may be used for ordinary work and steel rules, gages, etc., for fine work. Obtain distances from trued or finished surfaces whenever possible. In obtaining inside and outside diams., calipers may be used.

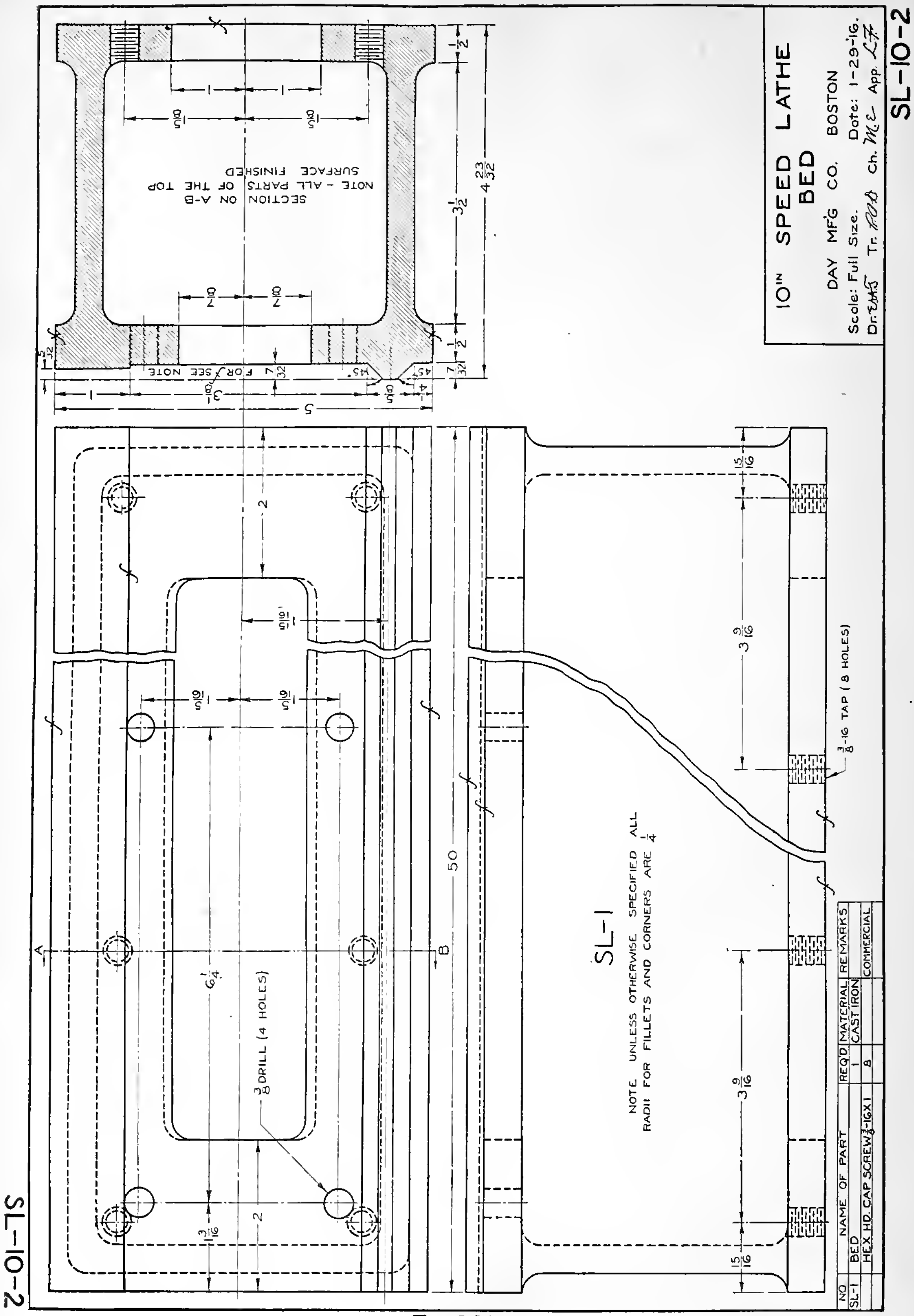
In an object of varying diams. (Fig. 174(a)), measure the diams. at a sufficient number of pts. and locate these diams. by measurements $\parallel$ to the axes. In measuring an irregular form, as the table leg (Fig. 198), it is necessary to establish a base line, as A-B, by means of a triangle or a carpenter's square, and to determine the lengths of $\perp$ offsets to it with a foot rule

In locating a circular hole, measure to edge of hole and add half its diam.

In ordinary finished surfaces, take the nearest 32d; in rough work, the nearest 16th; in finely finished objects and parts, absolute exactness is necessary.

105. Making Scale Drawings.

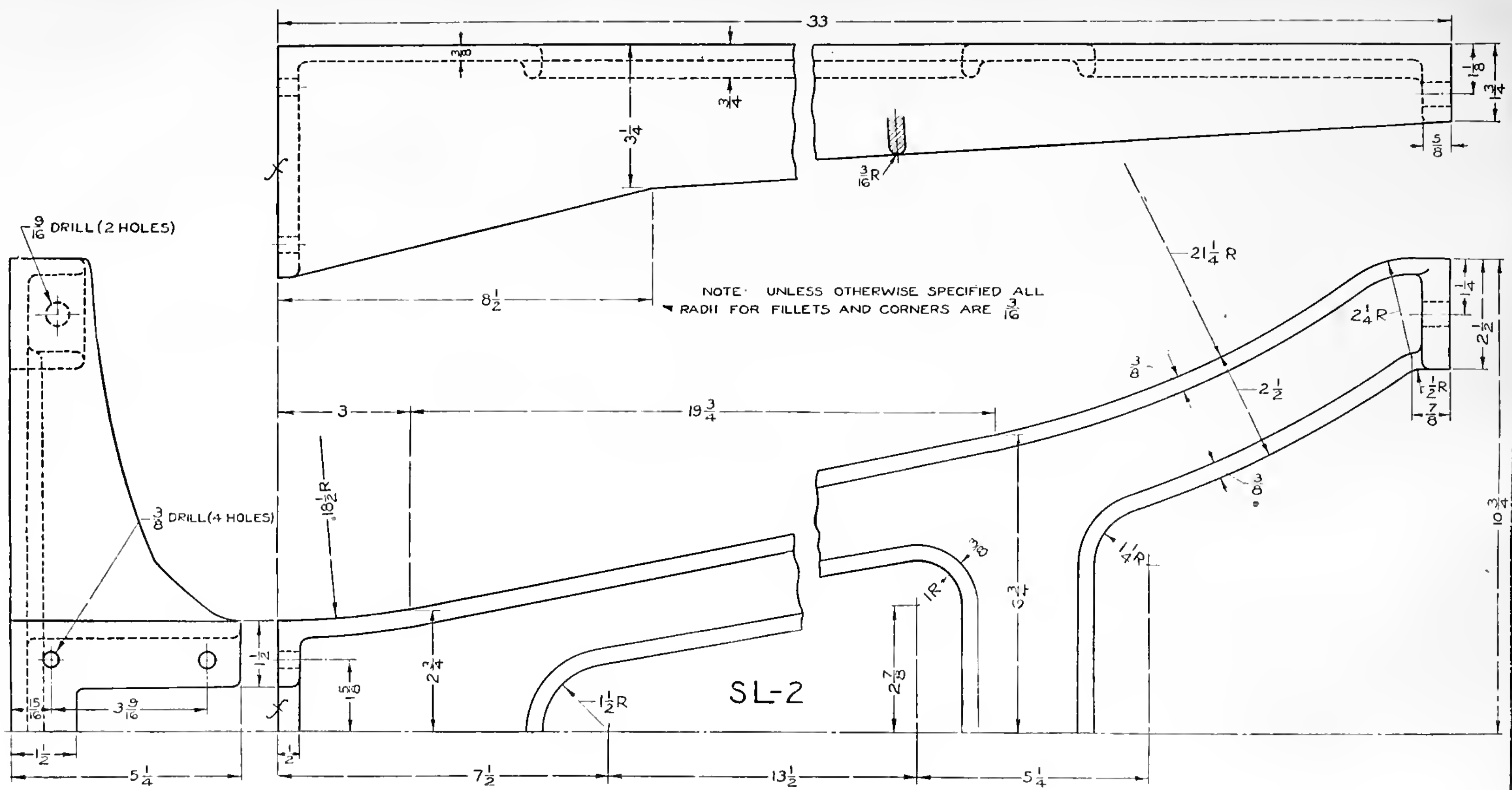
(a) Having completed the sketches, decide upon the number and arrangement of the views to be shown in the drawing, and the necessary scale. To aid in determining the scale and the locations of the chosen views upon the sheet, a rough *layout sketch* indicating the general outlines, main C. Ls., and margins, should be made. Thus, from the layout (Fig. 207) for the bearing shown in Fig. 208, it will be seen that the minimum space required horizontally, not including spaces between views and from margins, will be $2a + 2b$. Similarly, that required vertically will be $c + d + 2b$. From these two sets of



10IN SPEED LATHE
BED
DAY MF'G CO. BOSTON
Scale: Full Size. Date: 1-29-16.
SL-10-2
SECTION ON A-B
NOTE - ALL PARTS OF THE TOP SURFACE FINISHED
FOR SEE NOTE
3/8 DRILL (4 HOLES)
3/8-16 TAP (8 HOLES)
SL-1
NOTE UNLESS OTHERWISE SPECIFIED ALL RADII FOR FILLETS AND CORNERS ARE 1/4
NO | NAME OF PART | REQ'D | MATERIAL | REMARKS
SL-1 | BED | 1 | CAST IRON
HEX HD. CAP SCREW 3/8-16X1 | 8 | COMMERCIAL
SL-10-2

Fig. 203

SL-10-3



NO	NAME OF PART	REQ'D	MATERIAL	REMARKS
SL-2	LEG	2	CAST IRON	
	LAG SCREW $\frac{1}{2}$ X $2\frac{1}{2}$	4		COMMERCIAL
	PUNCHED WASHER $\frac{1}{2}$	4		COMMERCIAL

10IN SPEED LATHE
LEG

DAY MF'G CO. BOSTON

Scale: 6" = 1 Ft   Date: 1-29-'16.

Dr EMS Tr. R.A.D Ch. ME App. LF

SL-10-3

FIG. 204

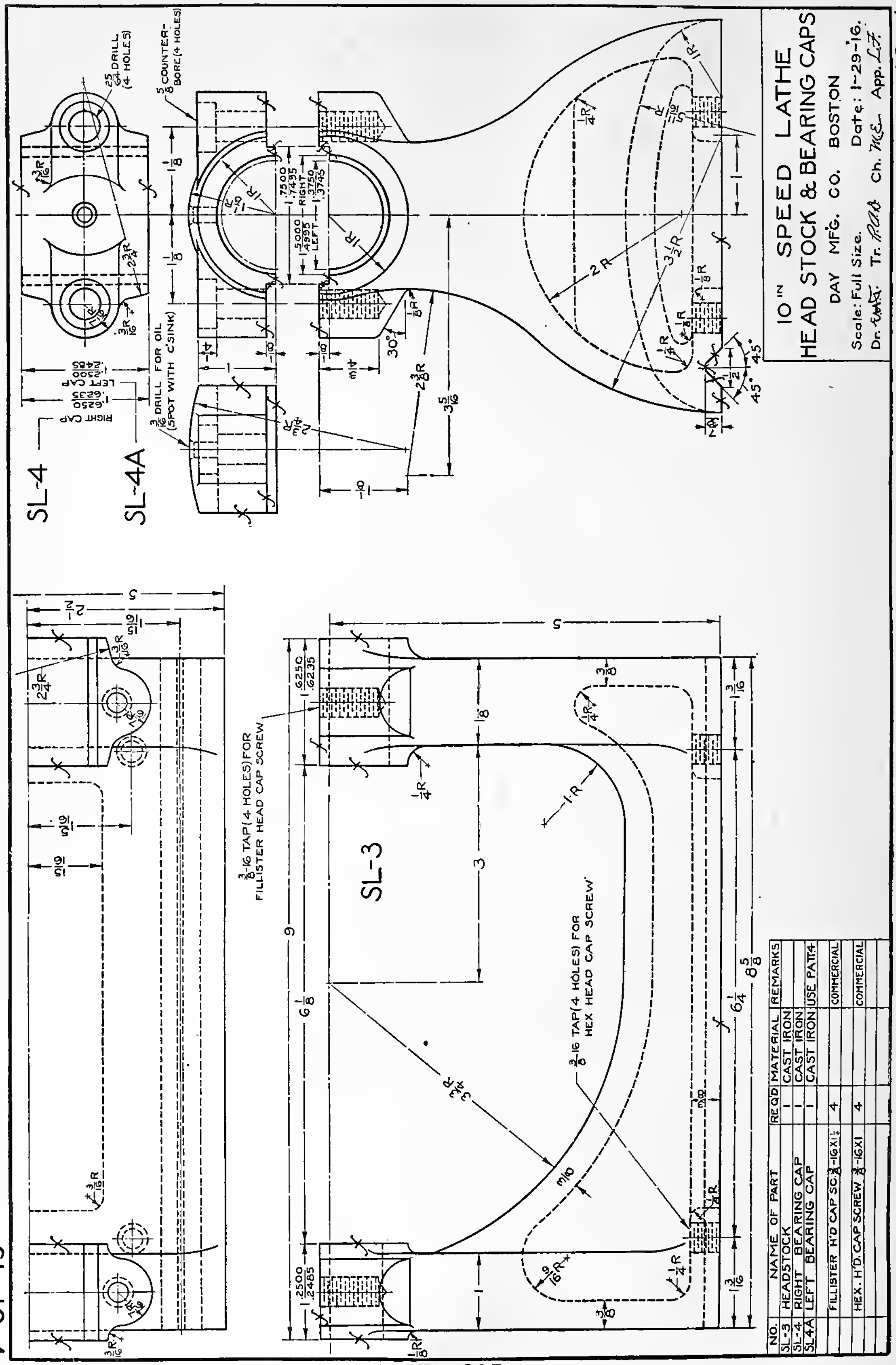
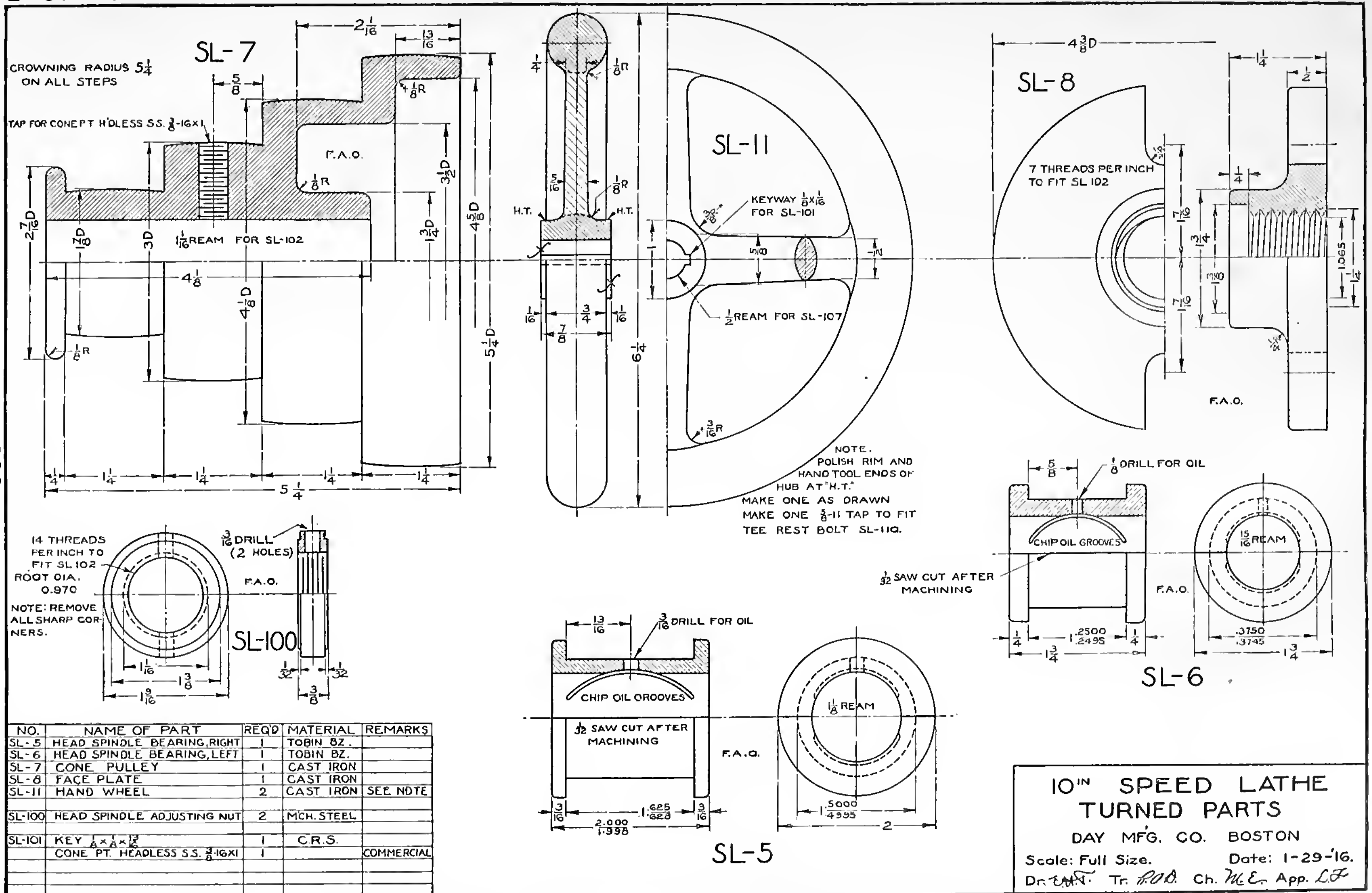

SL-10-4
10" SPEED LATHE
HEAD STOCK & BEARING CAPS
DAY MFG. CO. BOSTON
Scale: Full Size. Date: 1-29-16.
Dr. Tr. Ch. App.
SL-3
SL-4
SL-4A
3/8-16 TAP (4 HOLES) FOR FILLISTER HEAD CAP SCREW
3/8-16 TAP (4 HOLES) FOR HEX HEAD CAP SCREW
25/64 DRILL (4 HOLES)
5/8 COUNTER-BORE (4 HOLES)
3/16 DRILL FOR OIL (SPOT WITH C'SINK)
RIGHT CAP
LEFT CAP
NO. | NAME OF PART | REQ'D | MATERIAL | REMARKS
SL-3 | HEADSTOCK | 1 | CAST IRON |
SL-4 | RIGHT BEARING CAP | 1 | CAST IRON |
SL4A | LEFT BEARING CAP | 1 | CAST IRON | USE PATT.4
FILLISTER H'D CAP SC. 3/8-16X1 1/4 | 4 | COMMERCIAL
HEX. H'D. CAP SCREW 3/8-16X1 | 4 | COMMERCIAL
SL-10-4

Fig. 205



NO.	NAME OF PART	REQ'D	MATERIAL	REMARKS
SL-5	HEAD SPINDLE BEARING, RIGHT	1	TOBIN BZ.	
SL-6	HEAD SPINDLE BEARING, LEFT	1	TOBIN BZ.	
SL-7	CONE PULLEY	1	CAST IRON	
SL-8	FACE PLATE	1	CAST IRON	
SL-11	HAND WHEEL	2	CAST IRON	SEE NOTE
SL-100	HEAD SPINDLE ADJUSTING NUT	2	MCH. STEEL	
SL-101	KEY ⅛×⅛×13/16	1	C.R.S.	
	CONE PT. HEADLESS S.S. ⅜-16×1	1		COMMERCIAL

FIG. 206

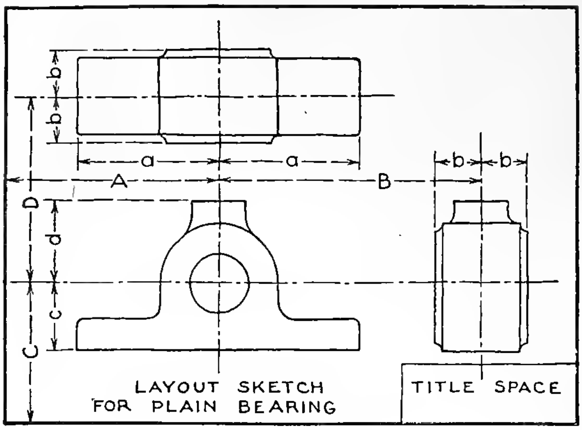


FIG. 207

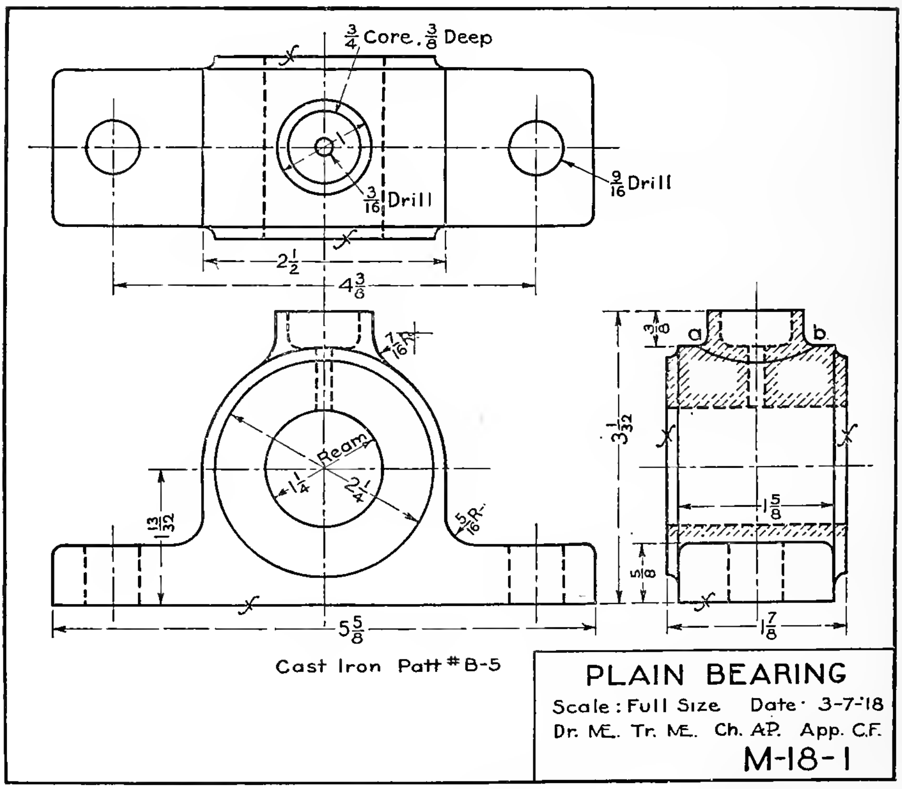
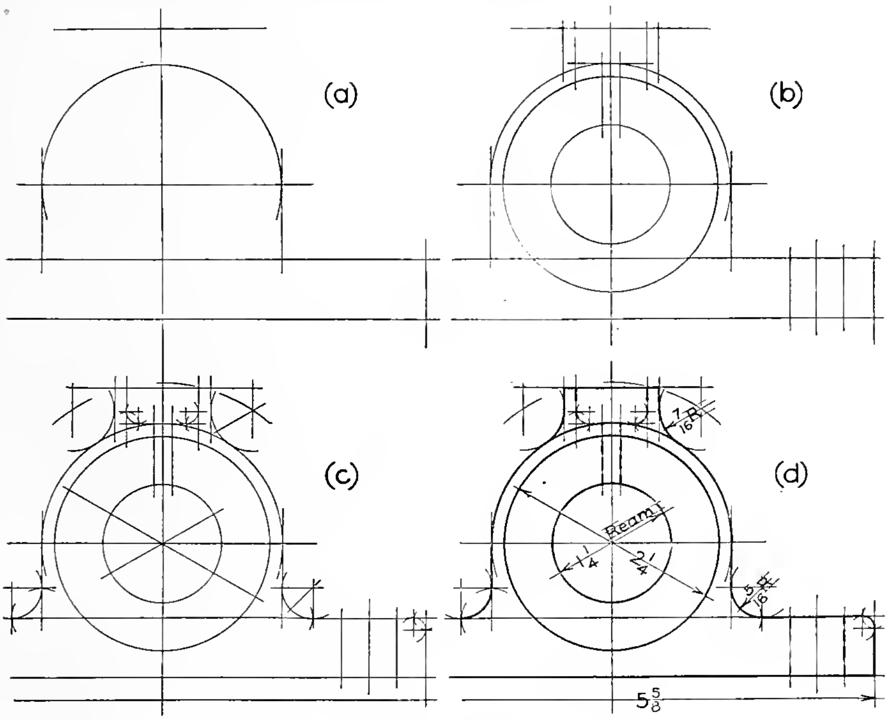


FIG. 208

dimensions, with due allowance for spaces and title, the scale may be determined, as in Art. 100(c). Having decided this, the dimensions A, B, C, and D for the locations of the C. Ls., should be estimated, proper allowance being made where necessary to preserve a well-balanced sheet.

The same general directions should be observed in all drawings, as lack of provisions for the necessary views, etc., may lead to errors impossible to rectify without re-drawing the entire sheet.

(b) Having completed the layout, the scale drawing (Fig. 208) may be begun. Four stages in penciling are indicated in Fig. 209. For general working instructions, see Art. 3. In drawing from objects, the detail drawings are first made and the general drawing built up, piece by piece, from them. In designing



FOUR STAGES IN PENCILING

FIG 209

or planning objects to be built, the general drawing is usually first begun and the detail drawings worked out from it. In some cases it is necessary to carry along both detail and general drawings at the same time.

106. Tracing and Blue-printing.

(a) Instead of inking the pencil drawing, the finished drawing is usually obtained by tracing in ink upon tracing linen or paper fastened over the original. This *tracing* is then filed as the permanent record of the construction and used for making *blue-prints* or other copies for shop and general use.

The original is sometimes penciled directly upon the tracing material.

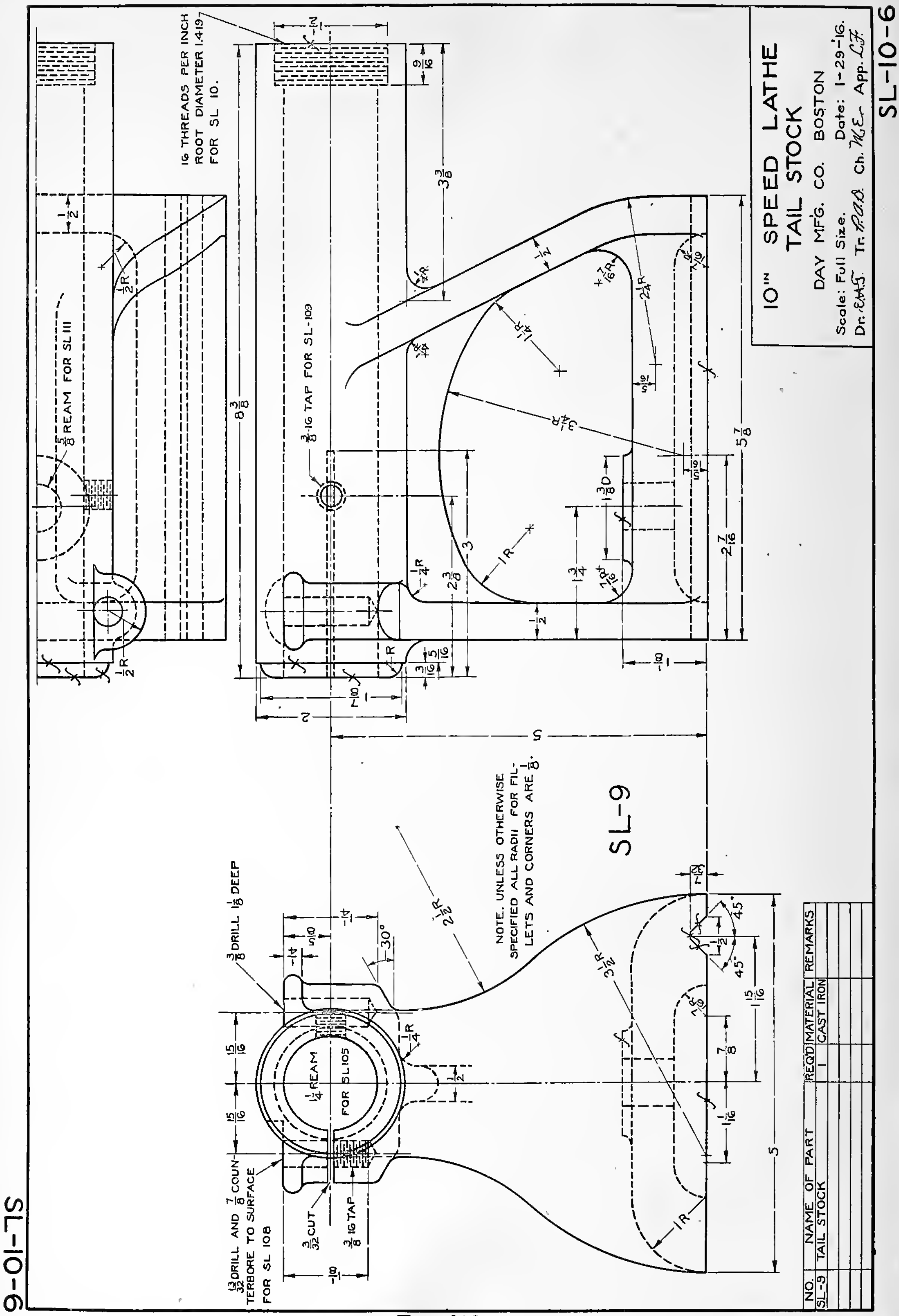

SL-10-6
10" SPEED LATHE
TAIL STOCK
DAY MFG. CO. BOSTON
Scale: Full Size. Date: 1-29-16.
SL-9
16 THREADS PER INCH ROOT DIAMETER 1.419 FOR SL 10.
5/8 REAM FOR SL 111
3/8-16 TAP FOR SL-109
3/8 DRILL 1 1/8 DEEP
13/32 DRILL AND 7/8 COUNTERBORE TO SURFACE FOR SL 108
3/32 CUT
3/8 16 TAP
1 1/4 REAM FOR SL 105
NOTE. UNLESS OTHERWISE SPECIFIED ALL RADII FOR FILLETS AND CORNERS ARE 1/8.
NO. NAME OF PART REQ'D MATERIAL REMARKS
SL-9 TAIL STOCK 1 CAST IRON

FIG. 210

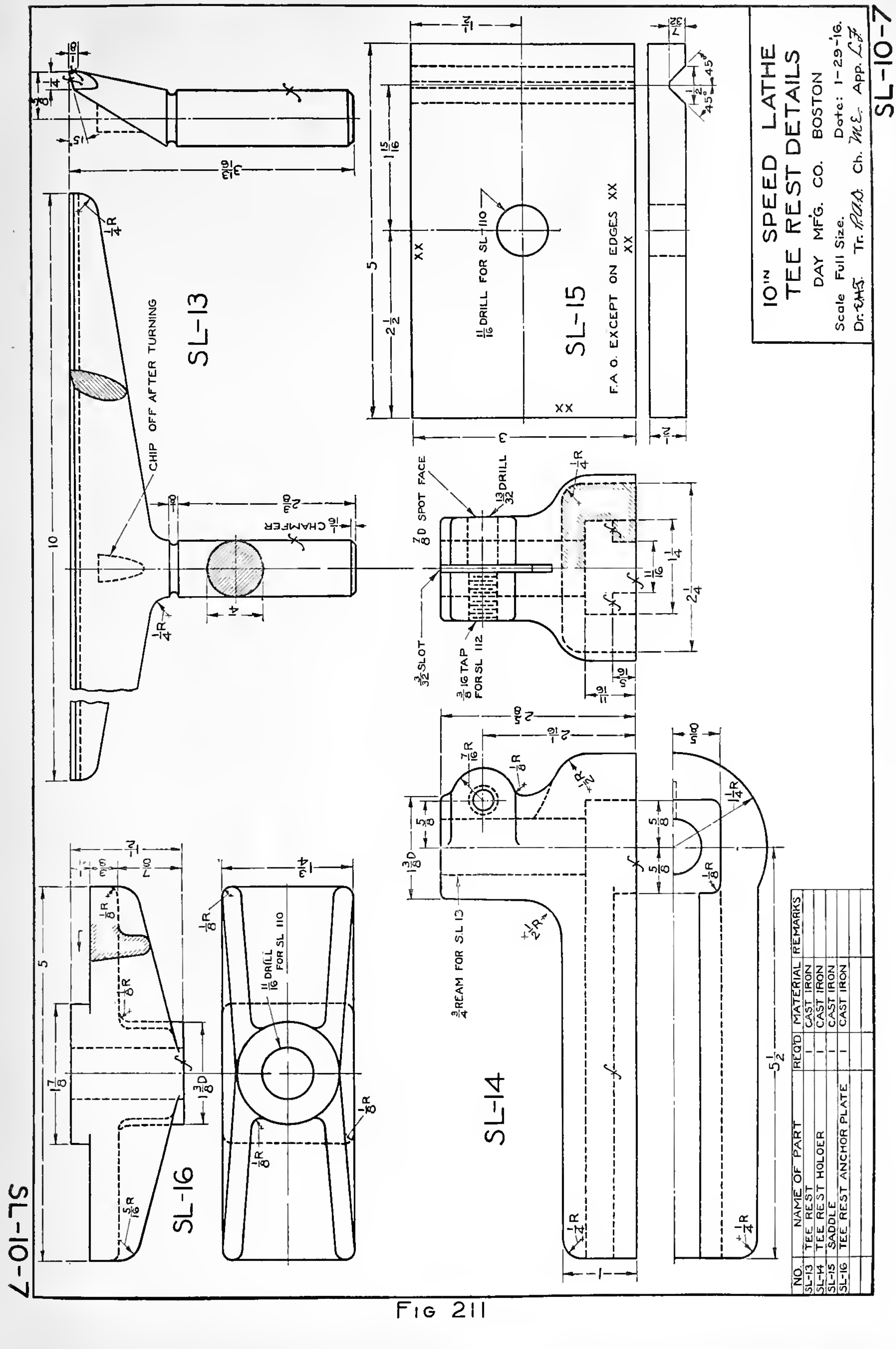

10IN SPEED LATHE
TEE REST DETAILS
DAY MFG. CO. BOSTON
Scale Full Size. Date: 1-29-'16.
SL-10-7
SL-13
SL-14
SL-15
SL-16
CHIP OFF AFTER TURNING
F.A.O. EXCEPT ON EDGES XX
11/16 DRILL FOR SL-110
3/4 REAM FOR SL 13
NO. | NAME OF PART | REQ'D | MATERIAL | REMARKS
SL-13 | TEE REST | 1 | CAST IRON
SL-14 | TEE REST HOLDER | 1 | CAST IRON
SL-15 | SADDLE | 1 | CAST IRON
SL-16 | TEE REST ANCHOR PLATE | 1 | CAST IRON

FIG 211

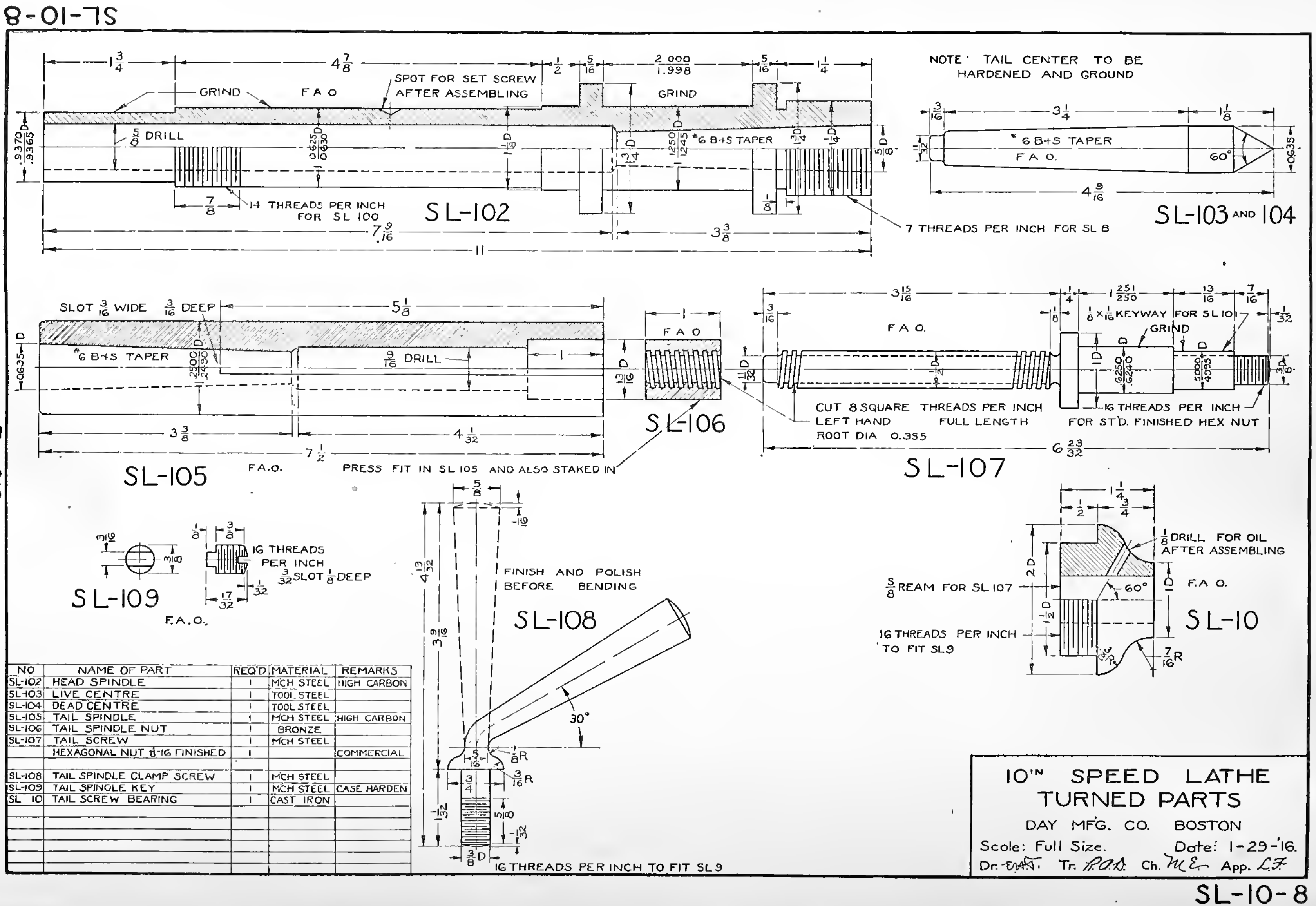
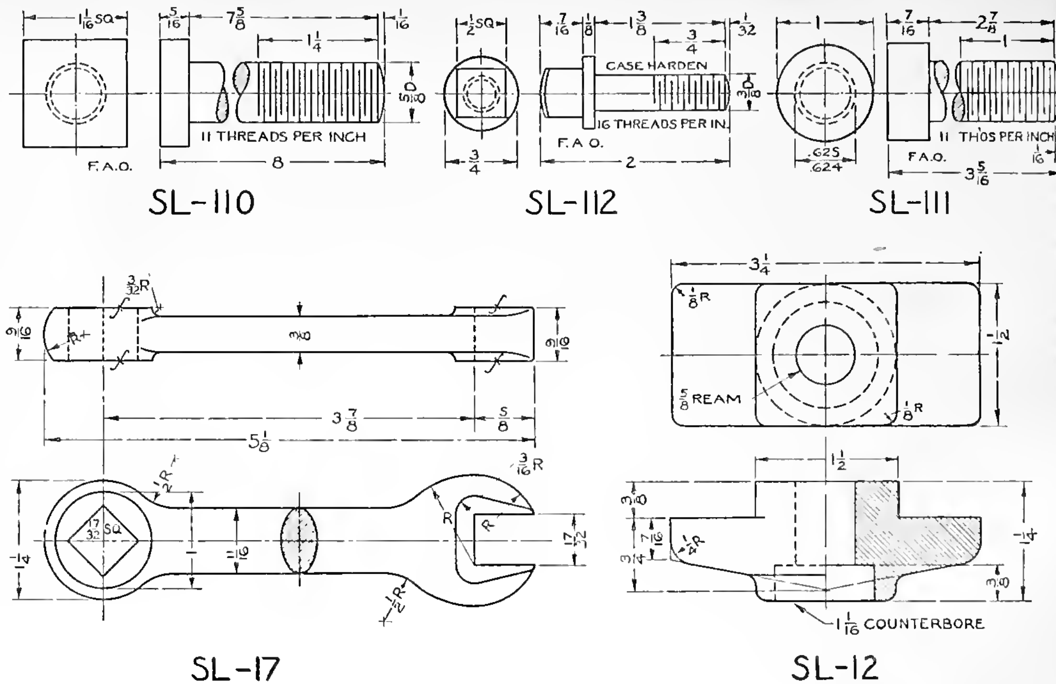

SL-10-8
NOTE: TAIL CENTER TO BE HARDENED AND GROUND
GRIND
F A O
SPOT FOR SET SCREW AFTER ASSEMBLING
5/8 DRILL
14 THREADS PER INCH FOR SL 100
*6 B+S TAPER
7 THREADS PER INCH FOR SL 8
SL-102
*6 B+S TAPER
F A O.
SL-103 AND 104
SLOT 3/16 WIDE 3/16 DEEP
*6 B+S TAPER
9/16 DRILL
SL-105
F.A.O.
PRESS FIT IN SL 105 AND ALSO STAKED IN
F A O
SL-106
F A O.
1/8 × 1/16 KEYWAY FOR SL 101
GRIND
CUT 8 SQUARE THREADS PER INCH LEFT HAND FULL LENGTH ROOT DIA 0.355
16 THREADS PER INCH FOR ST'D. FINISHED HEX NUT
SL-107
16 THREADS PER INCH 3/32 SLOT 1/8 DEEP
SL-109
F.A.O.
FINISH AND POLISH BEFORE BENDING
SL-108
16 THREADS PER INCH TO FIT SL 9
1/8 DRILL FOR OIL AFTER ASSEMBLING
5/8 REAM FOR SL 107
16 THREADS PER INCH TO FIT SL9
F.A O.
SL-10
NO | NAME OF PART | REQ'D | MATERIAL | REMARKS
SL-102 | HEAD SPINDLE | 1 | MCH STEEL | HIGH CARBON
SL-103 | LIVE CENTRE | 1 | TOOL STEEL |
SL-104 | DEAD CENTRE | 1 | TOOL STEEL |
SL-105 | TAIL SPINDLE | 1 | MCH STEEL | HIGH CARBON
SL-106 | TAIL SPINDLE NUT | 1 | BRONZE |
SL-107 | TAIL SCREW | 1 | MCH STEEL |
| HEXAGONAL NUT 5/8-16 FINISHED | 1 | | COMMERCIAL
SL-108 | TAIL SPINDLE CLAMP SCREW | 1 | MCH STEEL |
SL-109 | TAIL SPINDLE KEY | 1 | MCH STEEL | CASE HARDEN
SL 10 | TAIL SCREW BEARING | 1 | CAST IRON |
10" SPEED LATHE
TURNED PARTS
DAY MFG. CO. BOSTON
Scale: Full Size. Date: 1-29-'16.
SL-10-8

Fig. 212

SL-10-9

NO.	NAME OF PART	REQ'D	MATERIAL	REMARKS	SHEET
SL-1	BED	1	CAST IRON		SL-10-2
SL-2	LEG	2	CAST IRON		SL-10-3
SL-3	HEADSTOCK	1	CAST IRON		SL-10-4
SL-4	RIGHT BEARING CAP	1	CAST IRON		SL-10-4
SL-4A	LEFT BEARING CAP	1	CAST IRON	USE PATT. 4	SL-10-4
SL-5	HEAD SPINDLE BEARING, FRONT	1	TOBIN BZ.		SL-10-5
SL-6	HEAD SPINDLE BEARING, REAR	1	TOBIN BZ.		SL-10-5
SL-7	CONE PULLEY	1	CAST IRON		SL-10-5
SL-8	FACE PLATE	1	CAST IRON		SL-10-5
SL-9	TAIL STOCK	1	CAST IRON		SL-10-6
SL-10	TAIL SCREW BEARING	1	CAST IRON		SL-10-8
SL-11	HAND WHEEL	2	CAST IRON		SL-10-5
SL-12	TAILSTOCK ANCHOR PLATE	1	CAST IRON		SL-10-9
SL-13	TEE REST	1	CAST IRON		SL-10-7
SL-14	TEE REST HOLDER	1	CAST IRON		SL-10-7
SL-15	SADDLE	1	CAST IRON		SL-10-7
SL-16	TEE REST ANCHOR PLATE	1	CAST IRON		SL-10-7
SL-17	TEE REST WRENCH	1	WROT IRON		SL-10-9
SL-100	HEAD SPINDLE ADJUSTING NUT	2	MCH STEEL	FOR SL-102	SL-10-5
SL-101	HAND WHEEL KEY	1	C.R.S.	FOR SL-11	SL-10-5
SL-102	HEAD SPINDLE	1	MCH STEEL	HIGH CARBON	SL-10-8
SL-103	LIVE CENTER	1	TOOL STEEL		SL-10-8
SL-104	DEAD CENTER	1	TOOL STEEL		SL-10-8
SL-105	TAIL SPINDLE	1	MCH STEEL	HIGH CARBON	SL-10-8
SL-106	TAIL SPINDLE NUT	1	BRONZE		SL-10-8
SL-107	TAIL SCREW	1	MCH STEEL		SL-10-8
SL-108	TAIL SPINDLE CLAMP SCREW	1	MCH STEEL	FOR SL-9	SL-10-8
SL-109	TAIL SPINDLE KEY	1	MCH STEEL		SL-10-8
SL-110	TEE REST BOLT	1	MCH. STEEL		SL-10-9
SL-111	TAIL STOCK BOLT	1	MCH STEEL		SL-10-9
SL-112	TEE REST CLAMP SCREW	1	MCH STEEL	FOR SL-14	SL-10-9
	LAG SCREW 1/2 x 2-1/2	4	COMMERCIAL	FOR SL-2	SL-10-3
	PUNCHED WASHER 1/2	4	COMMERCIAL	FOR SL-2	SL-10-3
	FILLISTER HD. CAP SC. 3/8-16 x 1¼	4	COMMERCIAL	FOR SL-4	SL-10-4
	HEX HEAD CAP SCREW 3/8-16 x 1	12	COMMERCIAL	FOR SL-1+3	SL-10-2+4
	CONE PT. H'DLESS S.S. 3/8-16 x 1	1	COMMERCIAL	FOR SL-7	SL-10-5
	HEXAGONAL NUT 3/8-16, FIN.	1	COMMERCIAL	FOR SL-107	SL-10-8
	HEXAGONAL NUT 5/8-11	1	COMMERCIAL	FOR SL-111	SL-10-9



10" SPEED LATHE
DETAILS & BILL OF MATERIAL
DAY MF'G. CO. BOSTON
Scale. Full Size. Date: 1-29-'16.
Dr. EMJ Tr. R.O.D. Ch. M.E. App. L.F.

SL-10-9

FIG. 213

The dull side of tracing linen takes the ink better, but erasures can be made more readily upon the glazed side. Either will take the ink more readily if rubbed with a cloth and chalk powder. Penciling should be done on the dull side. Carry but little ink in the pen, and make the lines somewhat wider than ordinary as the lines print finer than those of the tracing.

As the linen contracts and expands unevenly, tracings that cannot be completed the same day should be inked by sections.

Make ink erasures with hard eraser, rubbing gently to avoid injury to the surface. Restore the smoothness by rubbing with soapstone or a smooth piece of bone. Pencil lines may be erased with soft eraser.

(b) Blue-prints are usually taken in a printing frame having a glass front and removable backboard. The tracing, or original drawing if on translucent material, is placed with the drawing side next to the glass and its under side in contact with the chemical coated surface of blue-print paper. The glazed side of the frame is then exposed to direct sunlight, which, penetrating the part of the tracing material not covered by the ink lines, causes the chemical not thus protected to change color and to adhere permanently to the paper, while that under the lines remains unchanged. After suitable exposure the paper is removed from the frame and soaked in water, which dissolves the unfixed chemical, leaving white lines on a blue ground.

107. Checking Drawings. It is customary not to permit a drawing to be worked from until it has been checked by a careful, systematic examination, and approved by the head draftsman. In checking, it is well to assume everything to be incorrect until proved to the contrary. The following order may be observed:—

See that each piece has been represented and that its views are properly related.

Check views of each piece for correct and adequate description of form and construction.

Note if C. Ls. and all necessary dimensions and notes are given.

Scale every dimension, and verify overall dimensions by computation.

Compare the figures on all parts that are to fit together.

Check measurements in details and assembly and note if they agree.

Finally, see that all items required to be recorded in the title and bill of material are complete and correct.

108. Reading Drawings. Ability to read working drawings rapidly and intelligently is quite as important as skill in making them. This ability can be acquired through the study of such drawings and comparison with the objects represented; through the execution of drawings from objects; through the making of mechanical pictorial drawings and developments, from good examples; and by making the objects, that is, working from drawings.

In reading a drawing, first fix in mind the general shape of the main body of the object, observing if the outline shows it to be rectangular, cylindric, etc., or a modification of such forms. Then observe modifications of the general shape, proceeding from the more important details down to the minor details.

Note carefully the conventional methods employed in the representation and complete mentally the graphic statement of what is required.

Endeavor to visualize the object; to see in each view, not mere lines, but the object itself as if standing out of the paper. Regard the front view as the object directly in front of you; in looking at the top view imagine yourself looking down upon the object; in looking at the side view imagine yourself as viewing the object in a direction at right ∠s to the front, and so on.

Finally, note the dimensions, and specifications as to materials, finish, etc. All information as to sizes should be obtained from the figured dimensions and specifications; rarely by measuring the drawing itself.

It is evident that full knowledge of the form, size, and relation of the lines and surfaces of each part of the object represented can be secured only through the information shown in all the views taken together.

CHAPTER XI

HELICAL CURVES, THREADED PARTS, AND SPRINGS

109. Helices. If a pt., A (Fig. 214) be imagined to move along the generating line, A-12, of a surface of revolution, while the line itself revolves about the axis, the pt. will generate a line of double curvature called a *helix*.

The distance that the pt. advances, measured || to the axis, during one revolution of the line, is called the *pitch* of the helix.

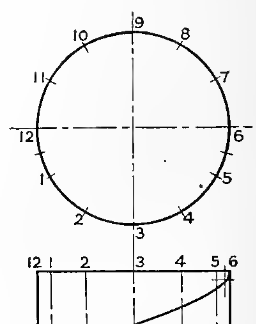
If the rate of motion of the pt. and generating line of a cylindric helix be uniform, that is, if the pt. advances $\frac{1}{4}$, $\frac{1}{2}$, or other fractional part of the pitch distance during the same fractional part of a turn, the helix is *uniform* or *equable;* if otherwise, it is *variable.*

Again the curve is a *right-hand* or *left-hand helix,* according as the generating pt. rises to the right or to the left in the front half of a turn when the axis is vert.

The helix has many applications in mechanical and architectural design, notably in screw threads, some forms of springs, winding stair rails, etc.

(a) To DRAW A RIGHT-HAND EQUABLE CYLINDRIC HELIX. Fig. 214. Assume and represent equidistant positions of the generating element, as 1, 2, 3, etc. Divide the pitch distance, as A-A^{12}, into the same number of equal parts and draw hors. through the pts. of division to cut the elements at A^1, A^2, A^3, etc. Assuming A to be the generating pt., A^1, A^2, A^3, etc., will be twelve pts. of the desired curve, for evidently when the generating element has made $\frac{1}{12}$ of a revolution the advancing pt. A will have moved $\frac{1}{12}$ of the pitch distance and will, therefore, be in the element 1 at A^1. When the element has moved $\frac{1}{2}$ a revolution the pt. A will have moved $\frac{1}{2}$ of the pitch distance and will be in the element 6 at A^6, and so on.

As the curvature is more abrupt at the outer elements, additional pts. should be determined by sub-division as shown. Having fixed the pts. with the needle, trace the helix through them freehand.



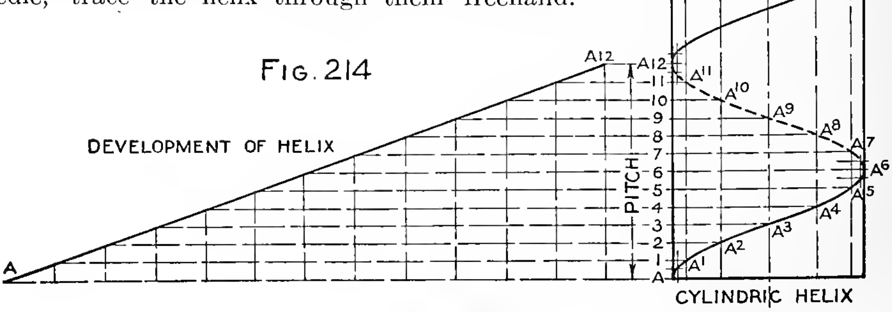


FIG. 214

Points for other turns of the curve may be located by stepping off the pitch distance upon the elements, from the pts. of the first turn. The manner of obtaining parallel or double helices is evident; also the method of drawing conic or other helices.

(b) In ruling and inking the helix observe directions given in Art. 18(a). When several cylindric helices of the same pitch are to be drawn, a templet of a half turn, as $A\text{-}A^6$, may be made.

(c) The development of a cylindric helix of one turn is the hypotenuse of a right △ whose base is equal to the circumference and whose altitude equals the pitch, as shown.

(d) Any desired motion of a pt. may be plotted in a development of a cylinder and then projected back to the view, as for example in designing a cam for converting circular into reciprocating motion.

110. Screw Threads. If a cylindric bar be revolved at a uniform velocity upon its axis, in a lathe, and the point of a V-shaped cutting tool be pressed against its surface and moved at a uniform rate parallel to the axis, the tool will cut a helical groove, V-shaped in section. If this groove be cut so that a similar projecting portion is left upon the bar, a *V screw thread* will be formed. Fig. 215(a).

Similarly, if a square groove be cut and a square projecting portion left upon the bar, a *square screw thread* will be formed. Fig. 215(c).

Fig. (b) illustrates a sec. of a V-threaded and Fig. (d) of a square-threaded hole. Observe that the helical lines of the threads correspond to the invisible lines of the screws.

The V thread is commonly used on screws for fastening purposes; the square thread generally on screws for transmitting motion in the direction of the axis. All other threads are modifications of the V and square forms.

A screw thread is *right-* or *left-hand* according as its helices are right- or left-hand. Thus a right-hand screw would turn around to the right (clockwise) in advancing or entering the part into which it is inserted.

The diameter of the top of the thread is called the *nominal diameter* of the screw. The diam. of the bottom of the thread is the *root diameter*. The distance from the root to the top of the thread measured $\perp$ to the axis is the *depth* of the thread. The distance between the centers of adjacent threads measured $\parallel$ to the axis is called the *pitch* of the thread. The term "pitch" is often used to designate the no. of threads per inch; thus "14 pitch" means 14 threads to the inch. The distance that the screw would advance in one turn is called the *lead* of the screw. In a single thread screw the lead equals the pitch; in a double or triple thread it is two or three times the pitch.

(a) Multiple Threads. Screws are generally right-hand and single thread as shown in Fig. 215 (a), (c). If the pitch of a screw having the diam. and thread sec. shown in Fig. (c) be made say two or three times as great, the increase in the depth would obviously be such as to weaken the screw at the root. There-

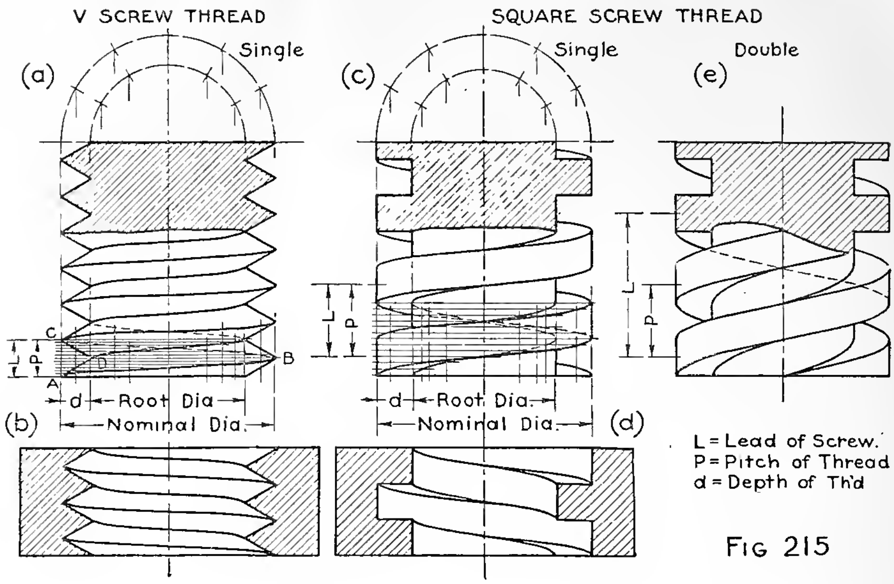


FIG 215

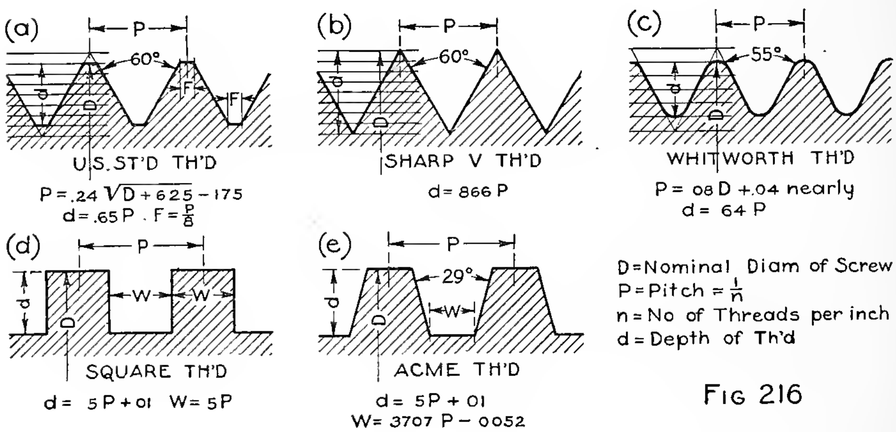


FIG 216

fore, in designing a screw of which the lead shall be two or three times the pitch, instead of cutting a single thread, a second or third independent parallel thread would be cut. Such would be a *double*, or *triple thread screw*.

Fig. (e) represents a right-hand double square thread of the same diam. and pitch as the single thread of Fig. (c).

Observe that in a single thread screw, the top on one side is diametrically opposite the bottom on the other, while in a double thread the tops are opposite.

(b) To DRAW A SCREW THREAD. The diam., pitch, and thread sec. being given, as in Fig. 215(a); first obtain the elevation and an end view, or half of revolved base of a cylinder whose diam. equals the nominal diam. of the screw. Lay off the pitch A-C and draw the sec. ADC. Then beginning at A, draw the helix A-B-C-, etc., for the top of the thread by Art. 110(a). To obtain the root helix, draw a semicircle in the base view concentric with the first, obtaining the rad. by projecting from D. Then beginning at D and using the same pitch, proceed as with the outer helix. Observe that the outlines of the thread come outside of the V sec. and are tangent to the helices. When the pitch is small, they practically coincide with the sec. outline.

(c) STANDARD PROPORTIONS. In the preceding figures, the threads were represented with large pitch in order to show the construction more clearly. The proportions of the threads most commonly used and the formulæ for obtaining them are given in Fig. 216. In this country the ∠ of the V thread is usually 60°, but for general work the tops and bottoms are flattened as shown in Fig. (a).

The following table gives the U. S. St'd no. of threads per inch, for diams. from $\frac{1}{4}''$ to $4\frac{1}{4}''$.

U. S. STANDARD SCREW THREADS

DIAM. SCREW	THDS. PER IN.	DIAM. SCREW	THDS. PER IN.	DIAM. SCREW	THDS. PER IN.	DIAM. SCREW	THDS. PER IN.	DIAM. SCREW	THDS. PER IN.
$\frac{1}{4}$	20	$\frac{5}{8}$	11	1	8	$1\frac{3}{4}$	5	3	$3\frac{1}{2}$
$\frac{5}{16}$	18	$\frac{11}{16}$	11	$1\frac{1}{8}$	7	$1\frac{7}{8}$	5	$3\frac{1}{4}$	$3\frac{1}{2}$
$\frac{3}{8}$	16	$\frac{3}{4}$	10	$1\frac{1}{4}$	7	2	$4\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{4}$
$\frac{7}{16}$	14	$\frac{13}{16}$	10	$1\frac{3}{8}$	6	$2\frac{1}{4}$	$4\frac{1}{2}$	$3\frac{3}{4}$	3
$\frac{1}{2}$	13	$\frac{7}{8}$	9	$1\frac{1}{2}$	6	$2\frac{1}{2}$	4	4	3
$\frac{9}{16}$	12	$\frac{15}{16}$	9	$1\frac{5}{8}$	$5\frac{1}{2}$	$2\frac{3}{4}$	4	$4\frac{1}{4}$	$2\frac{7}{8}$

On square threads the no. of threads per inch is commonly $\frac{1}{2}$ of the U. S. St'd. In drawing, the depth is made $\frac{P}{2}$.

The *Acme Standard* or *29° thread* is used for the same general purpose as the square thread. Threads per inch are likewise usually the same. In drawing, the angle is made 30°.

In the *Whitworth* or *British Standard*, threads per inch are, with a few exceptions, the same as U. S. St'd. See handbooks.

(d) Conventional Representation of Threads. The true drawing of the thread curves involves considerable labor and in small screws would be impossible. In large threads it is customary to substitute st. lines for the helices, as in Fig. 217. In invisible threads they are often omitted altogether.

V threads less than one inch diam. are usually represented as in Fig. 218 (a), (b), (c), (d). The methods (e), (f), (g), (h) are also used. The spacing is estimated by eye, without regard to the actual no. of threads per inch, but in methods (a), (b), (c), (d) the positions of the lines should indicate whether the screw is right- or left-hand. The thread of a long piece may be shown as in (i).

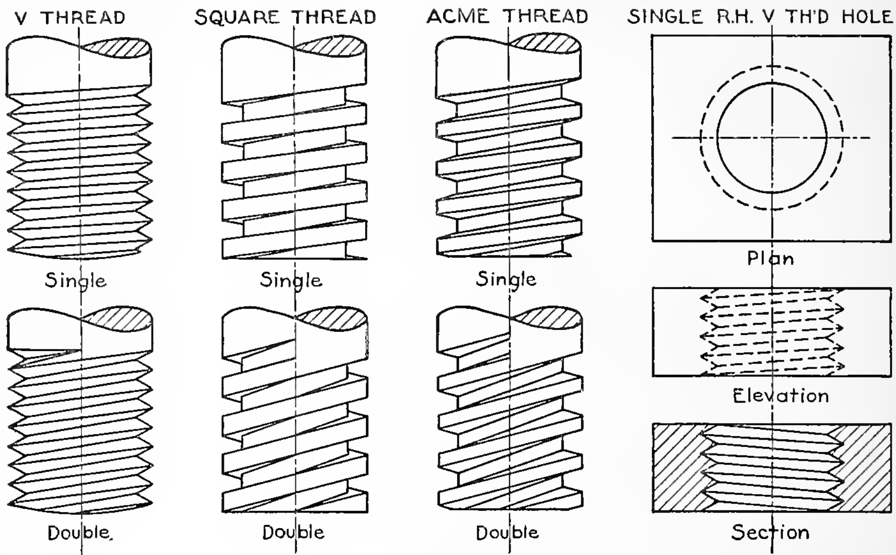


Fig 217

Small square threads are usually represented as in (j). The exact no. of threads per inch is shown unless the scale is very small.

A threaded hole is generally represented in the circular view as in (k), to distinguish it from a drilled hole; a drilled and threaded hole, as in (l).

The diam. of the outer ⊙ in each is equal to that of the bolt or screw; that of the smaller about equal to that of the root. Any of the methods of Fig. 218 may be used for the other views. On crowded drawings it is often best to use methods (d), (f), (h), or (m). It is better to omit the drawing of the threads beyond the screw end (see (n)), unless method (m) is used. The point made by the drill is usually shown.

Figs. (o) and (p) show methods of representing small pieces in sec. when V-threaded inside and outside.

(e) Dimensioning. Give the outside diam.; the no. of threads per inch, thus: 10Th, 10Thds., 10P., 10, or X: and the length of the threaded portion, from the end when chamfered, and from the curve when rounded. If the thread is other than right-hand and single, specify as indicated in Figs. (b), (c).

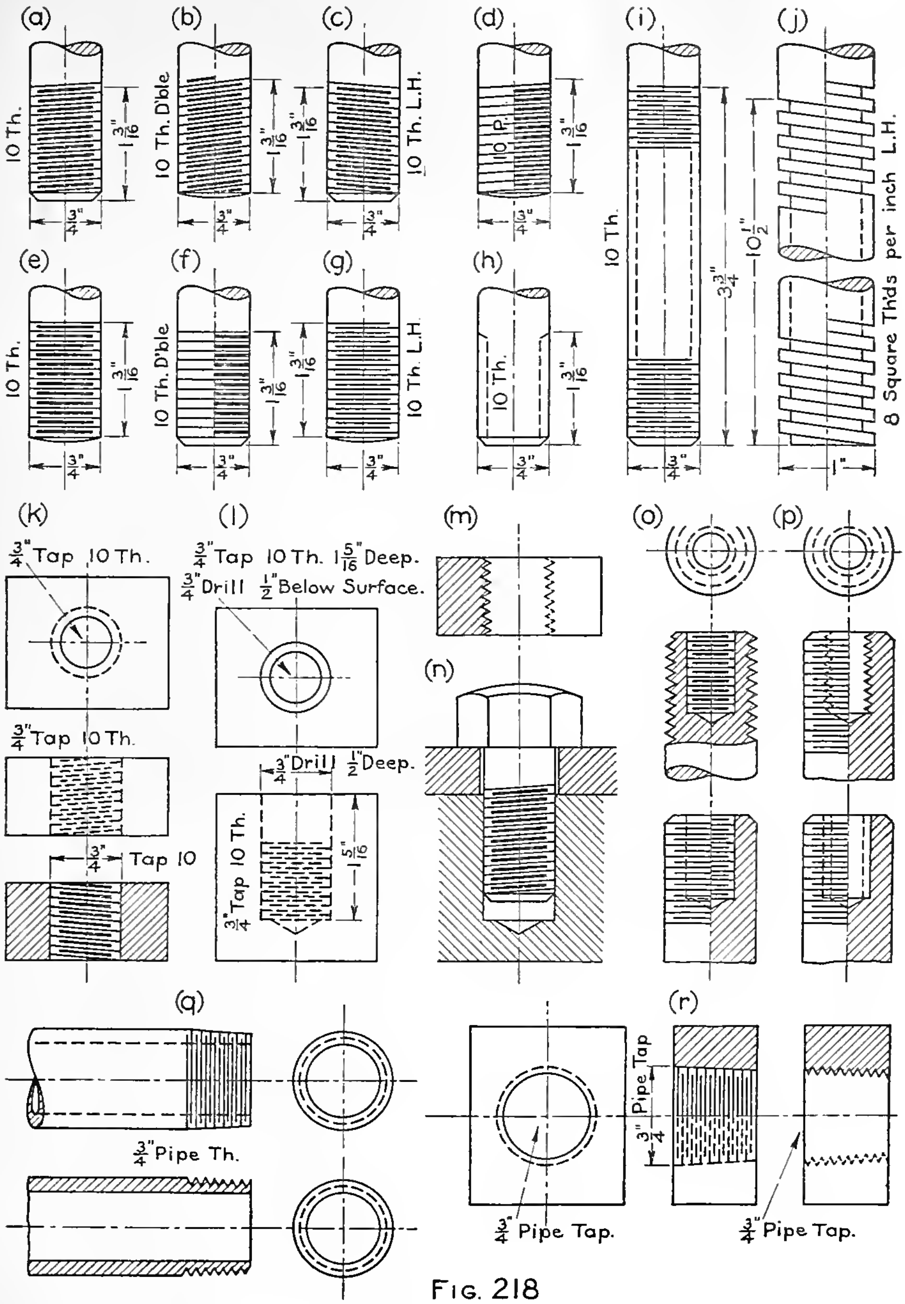

(a)
10 Th.
$1\frac{3}{16}$"
$\frac{3}{4}$"
(b)
10 Th. D'ble
(c)
10 Th. L.H.
(d)
10 P.
(i)
10 Th.
$3\frac{3}{4}$"
$10\frac{1}{2}$"
(j)
8 Square Th'ds per inch L.H.
1"
(e)
(f)
(g)
(h)
(k)
$\frac{3}{4}$" Tap 10 Th.
Tap 10
(l)
$\frac{3}{4}$" Tap 10 Th. $1\frac{5}{16}$" Deep.
$\frac{3}{4}$" Drill $\frac{1}{2}$" Below Surface.
$\frac{3}{4}$" Drill $\frac{1}{2}$" Deep.
$\frac{3}{4}$" Tap 10 Th.
$1\frac{5}{16}$"
(m)
(n)
(o)
(p)
(q)
$\frac{3}{4}$" Pipe Th.
(r)
$\frac{3}{4}$" Pipe Tap
$\frac{3}{4}$" Pipe Tap.

FIG. 218

In a threaded hole, give the depth, the diam. of the piece to be screwed into it, and no. of threads per inch. Indicate diam. and no. of threads of a tapped hole, as in Figs. (k), (l).

All parts shown V-threaded are generally understood to be U. S. St'd, unless otherwise specified; likewise when the no. of thds. is not given.

111. Pipe Threads. The threaded ends and holes of pipes and pipe fittings are tapered so that the parts may be screwed together more tightly and thus prevent leakage. The standard taper is $\frac{3}{4}''$ per foot. The thread ∠ is 60°, and the tops and bottoms are slightly rounded or flattened. The thread is usually represented by the conventional methods used for V screw threads. See Fig. 218 (q), (r).

The taper is commonly drawn slightly greater than the actual, to show at a glance that the threads are pipe threads. The sizes of pipes are stated by giving their nominal inside diams., which are somewhat less than the actual inside diams., as noted in the table. Pipe tapped holes are indicated by size of pipe tap required.

STANDARD WROUGHT IRON PIPE

NOMINAL INSIDE DIAM.	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	6
ACTUAL INSIDE DIAM.	.36	.49	.62	.82	1.05	1.38	1.61	2.07	2.47	3.07	3.55	4.03	4.51	5.05	6.07
ACTUAL OUTSIDE DIAM.	.54	.68	.84	1.05	1.32	1.66	1.90	2.38	2.88	3.50	4.00	4.50	5.00	5.56	6.63
THREADS PER IN.	18	18	14	14	$11\frac{1}{2}$	$11\frac{1}{2}$	$11\frac{1}{2}$	$11\frac{1}{2}$	8	8	8	8	8	8	8
DIAM. AT TOP OF THREAD AT END	.52	.62	.82	1.03	1.28	1.63	1.87	2.34	2.82	3.44	3.94	4.44	4.93	5.49	6.55

112. Bolts. The *heads* and *nuts* of machine bolts in common use are made *hexagonal*, or *square*, as in Fig. 219.

The hexagonal form is more generally used in machine construction, the square in heavy work. For ordinary work, the head and nut are chamfered or beveled at the outer end. For finished machinery they are usually rounded.

(a) STANDARD PROPORTIONS. Proportions of the U. S. St'd rough bolt-heads and nuts are given in the figure. They are generally used for the square also. There is no standard for the rad. R, nor for the bevel of the chamfers, but they are usually shown as in the figure.

(b) CONVENTIONAL REPRESENTATIONS OF HEXAGON HEADS AND NUTS. In the rounded head and nut, the curves of intersection of the sides and end are circular. In the view across corners, therefore, the curve c-d is concentric with a-b, while those of the oblique sides would be elliptic. Art. 77(a). The latter, however, are always described as circular.

Note that the outer curve in the nut begins at the hole instead of at the C. L.

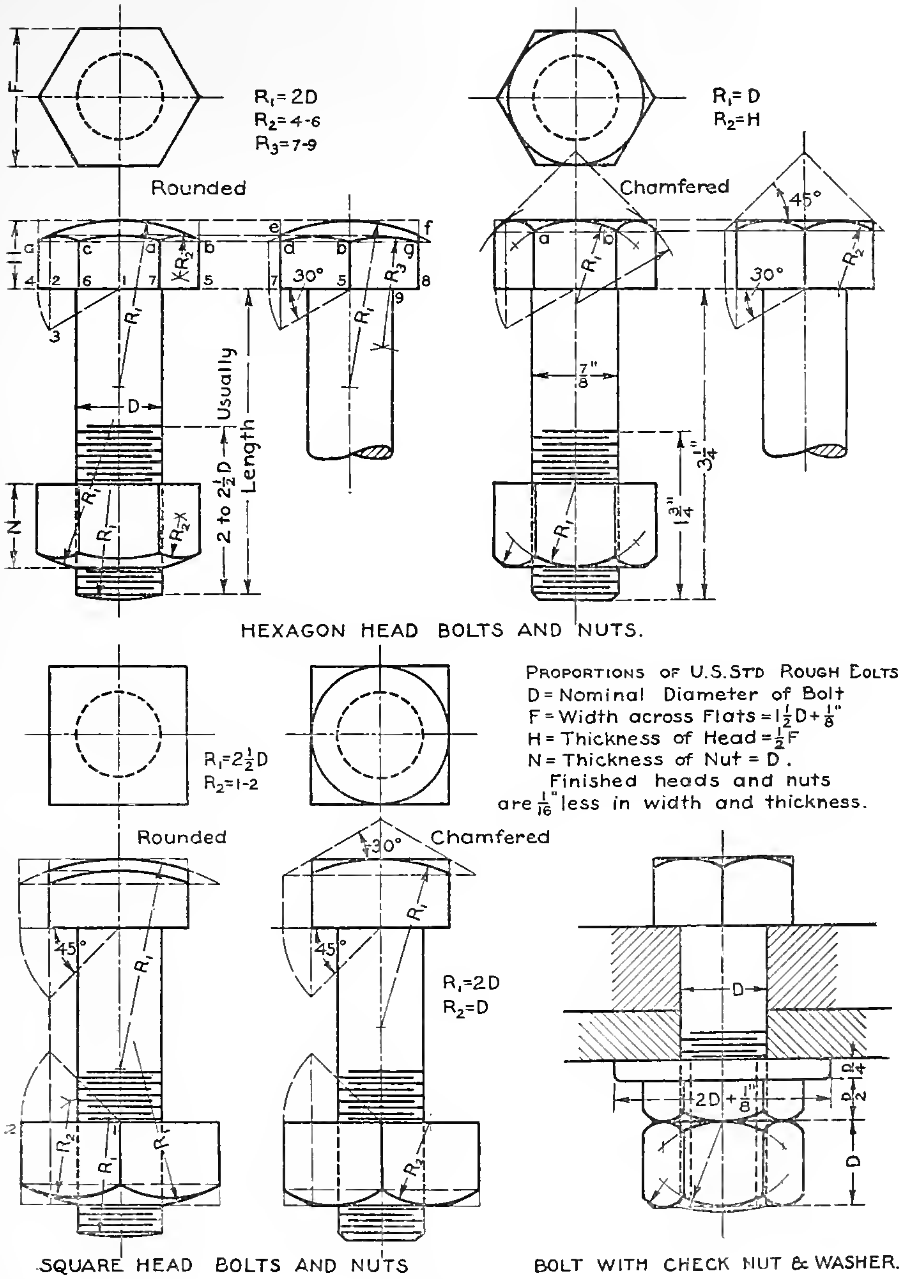

F
$R_1 = 2D$
$R_2 = 4\text{-}6$
$R_3 = 7\text{-}9$
Rounded
$R_1 = D$
$R_2 = H$
Chamfered
45°
30°
Usually
2 to $2\frac{1}{2}D$
Length
D
$\frac{7}{8}''$
$3\frac{1}{4}''$
$1\frac{3}{4}''$
N
HEXAGON HEAD BOLTS AND NUTS.
$R_1 = 2\frac{1}{2}D$
$R_2 = 1\text{-}2$
Proportions of U.S. Std Rough Bolts
D = Nominal Diameter of Bolt
F = Width across Flats = $1\frac{1}{2}D + \frac{1}{8}''$
H = Thickness of Head = $\frac{1}{2}F$
N = Thickness of Nut = D.
Finished heads and nuts are $\frac{1}{16}''$ less in width and thickness.
Rounded
30°
Chamfered
45°
$R_1 = 2D$
$R_2 = D$
$2D + \frac{1}{8}''$
$\frac{D}{4}$
$\frac{D}{2}$
SQUARE HEAD BOLTS AND NUTS
BOLT WITH CHECK NUT & WASHER.

Fig. 219

In the chamfered head and nut the curves of intersection of the sides and end, though in reality hyperbolic (Art. 77(c)), are likewise always described as circular. The outer line of the chamfer is often described by arcs concentric with a-b, as shown.

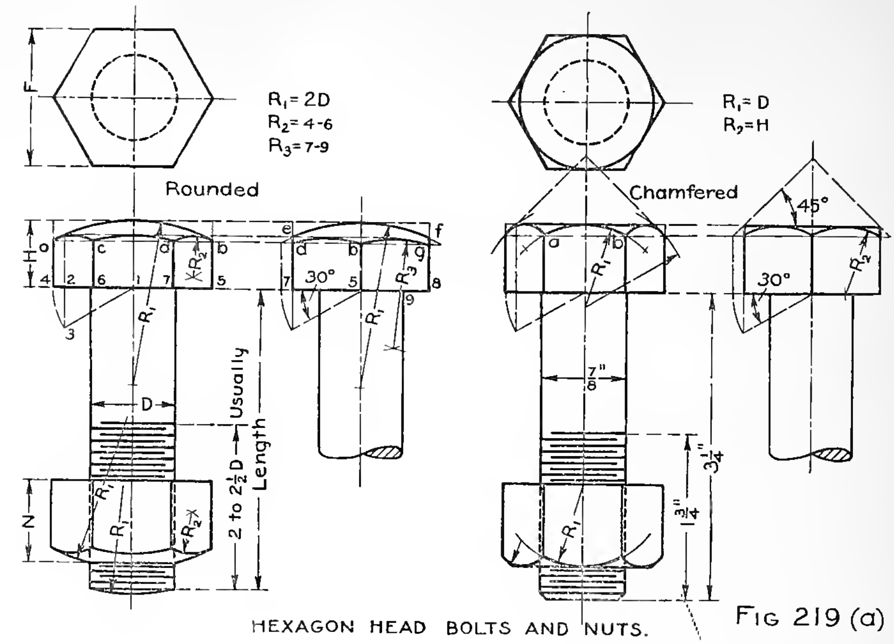


FIG 219 (a)

(c) TO DRAW THE VIEW ACROSS CORNERS OF THE ROUNDED HEXAGON HEAD AND NUT. Upon an indefinite line 4-5 set off 1-2 equal to $\frac{1}{2}$ F. Draw the $\perp$ 2-3 and the 30° line from 1. Then 2-3 will represent half of a revolved

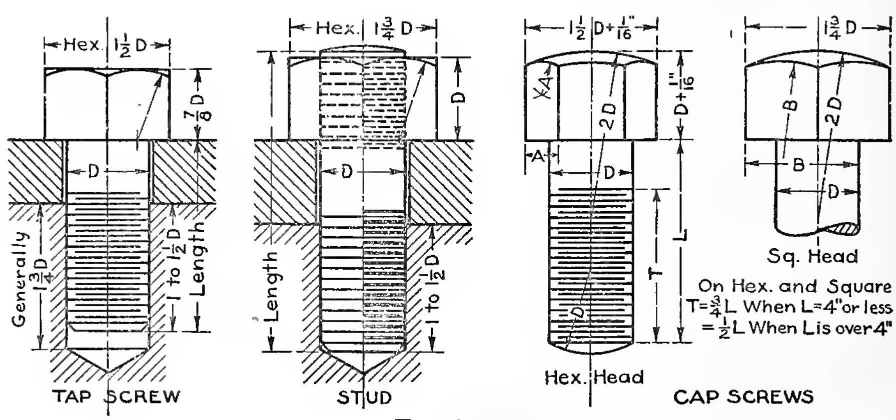


FIG. 220

side of the hexagon and 1-3 half of its long diam. Now set off 1-4 and 1-5 equal to 1-3, and 1-6 and 1-7 equal to 2-3, and draw 4-a, 5-b, 6-c, and 7-d. Next set off H and draw arc a-b determining the length of the ⊥s. Finally, draw arcs c-d, a-c, and d-b. In small drawings the long diam. may be made equal to 2 D. The method of drawing the nut is evident.

(d) To DRAW THE VIEW ACROSS FLATS OF THE ROUNDED HEXAGON HEAD AND NUT. Set off 7-8 equal to F, and draw 7-e and 8-f. Next set off H and draw arc e-f determining pts. e and f. Then determine pts. d, b, and g, as in Art. (c), and describe arcs d-b and b-g. The method of drawing the nut is evident.

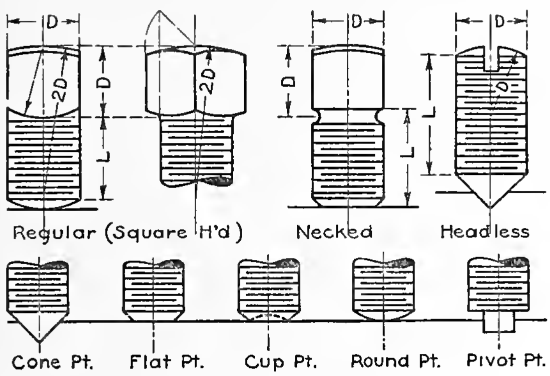


FIG. 221

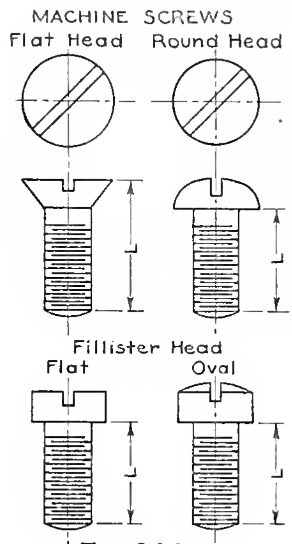


FIG. 222.

(e) To DRAW THE CHAMFERED HEAD AND NUT ACROSS CORNERS OR ACROSS FLATS. The method for each is evident from Arts. (c) and (d).

(f) SQUARE HEADS AND NUTS. The method of drawing the square head and nut is, in general, the same as for the hexagon.

(g) When drawn in connection with the parts held together, both heads and nuts should, as a rule, be represented across corners to show that proper allowance has been made for clearance; otherwise they should be shown across flats, as they are thus simpler to draw and to figure.

(h) Fig. 219 also illustrates a st'd hexagon bolt with *check nut and washer*. Both nuts are often made equal in thickness, $\frac{3}{4}$ D.

(i) DIMENSIONING. In a st'd bolt give the diam.; length of bolt from the under side of the head to extreme end, unless the end is rounded; and the length of the threaded portion.

In a special bolt give also the distance across flats, the thickness of head and nut and the no. of thds. per inch.

113. Screws. Fig. 220 represents a *tap screw* or *tap bolt;* a *stud bolt* or *stud,* and *hexagon* and *square head cap screws.*

A tap screw is similar to a st'd bolt without the nut; the end being screwed into a tapped hole.

A stud is used where frequent removal is not desirable, as in cylinder heads. One end is screwed permanently into a tapped hole and a st'd nut used on the other. A cap screw is a type of tap screw used where adjustment is necessary, as on bearing caps, etc.

Fig. 221 represents *set screws* which are used to prevent the motion of one piece by forcing the point against a second.

The form of point used is dependent upon the resistance desired.

Fig. 222 represents four types of *machine screws* which are from .06″ to .45″ in diam. and designated by gage number. Slots are drawn at 45° in end views for contrast with other lines. Tables of proportions of these and other forms of screws and bolts may be found in catalogs and engineers' handbooks. Fig. 223 represents *wood screws.*

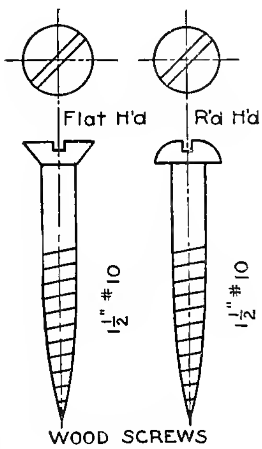


FIG 223

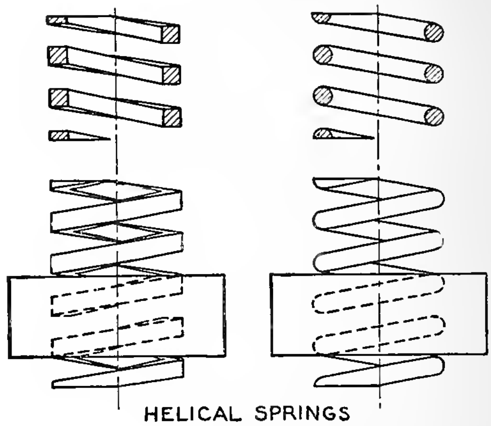


FIG. 224

114. Springs. Fig. 224 shows conventional representations of *helical springs.* In small secs. the helical lines are often omitted.

In dimensioning, give outside diam., gage of wire, and coils per inch when extended.